APPLICATIONS OF ACCELERATORS TO TUMOUR THERAPY - 2

Ugo Amaldi

University of Milano Bicocca and TERA Foundation

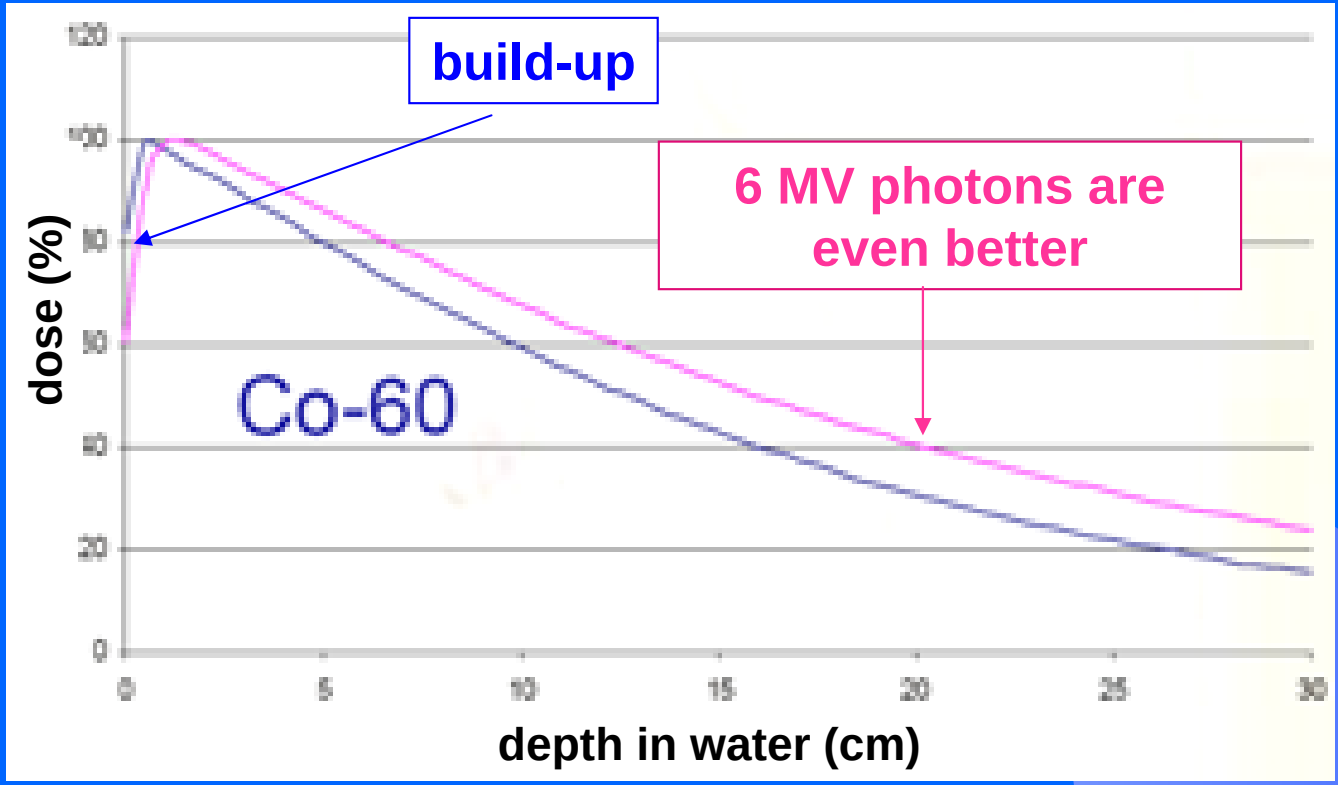
Conventional radiotherapy

The beginning of X-ray therapy

<u>Orthovoltage</u> (low energy) X-ray therapy began in January 1896.

Many complications because of the dose to the skin.

<u>Megavoltage</u> (high-energy) radiation in the 50s. Co-60 gamma spared the skin.



First Cobalt-60 'bomb' in Canada

1951 – first treatment at Victoria Hospital, London, Ontario

Cobalt-60 (1.2 MeV gammas)

has been produced for 50 years in CANDU reactors

After World War II: old and new 'cobalt bombs'

Cobalt source 2000

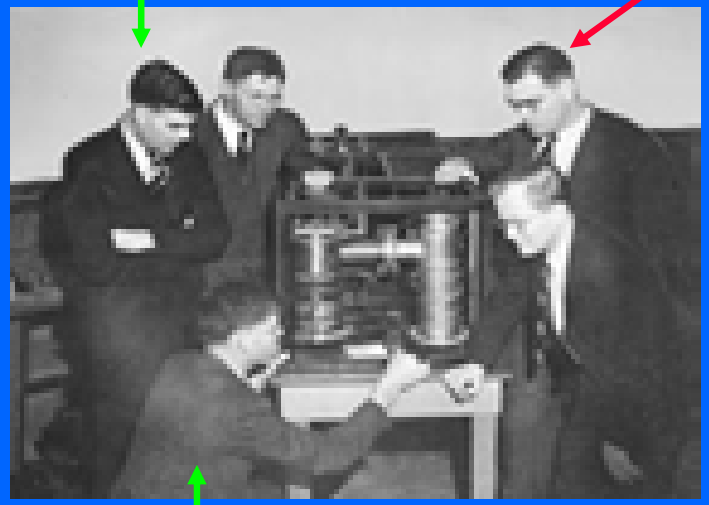
10 million patients treated with cobalt gamma rays

Important for developing countries

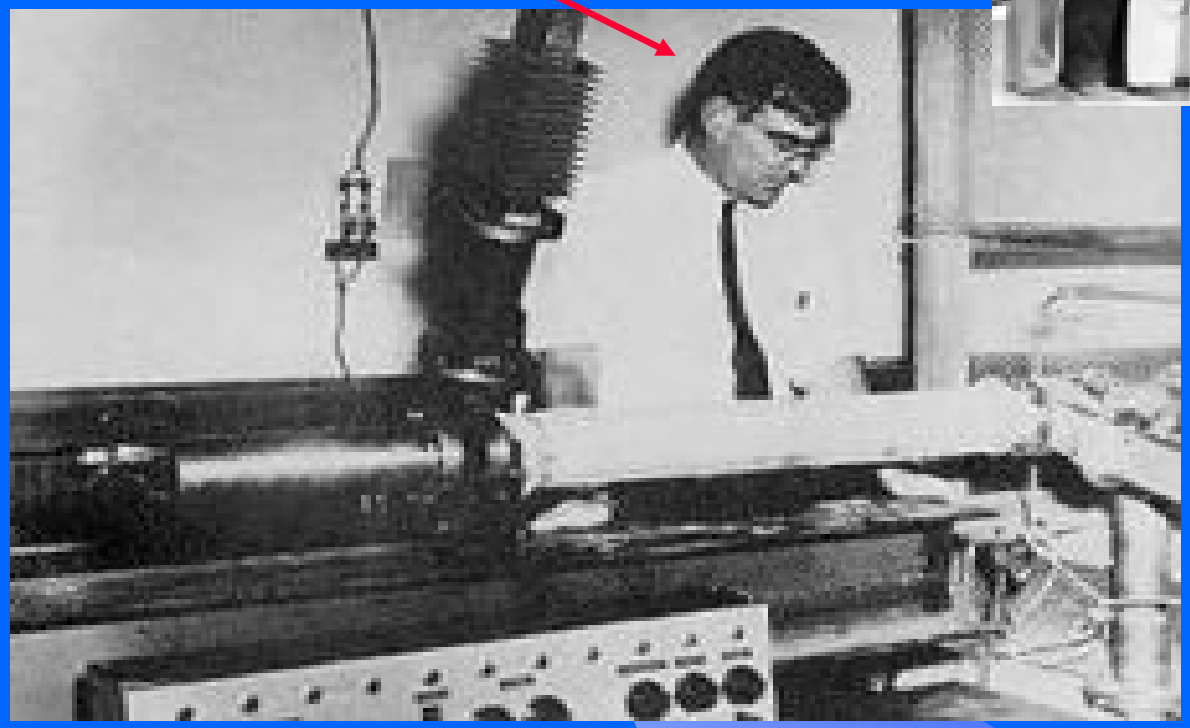
The electron linac

Sigurd Varian

William W. Hansen



Russell Varian

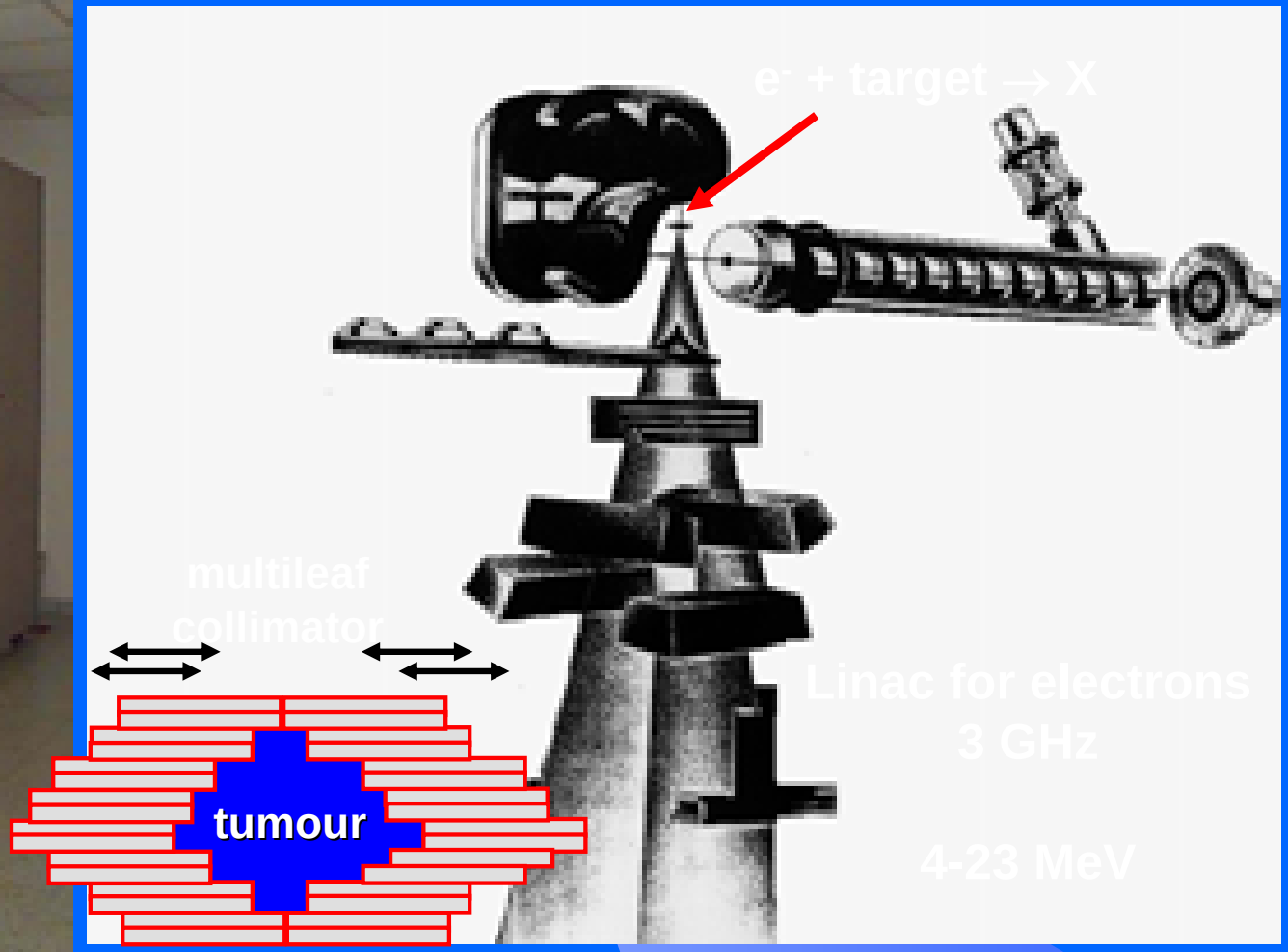


1939

Klystron invention

1947 - Stanford
The first linac for electrons
4.5 MeV and 3 GHz

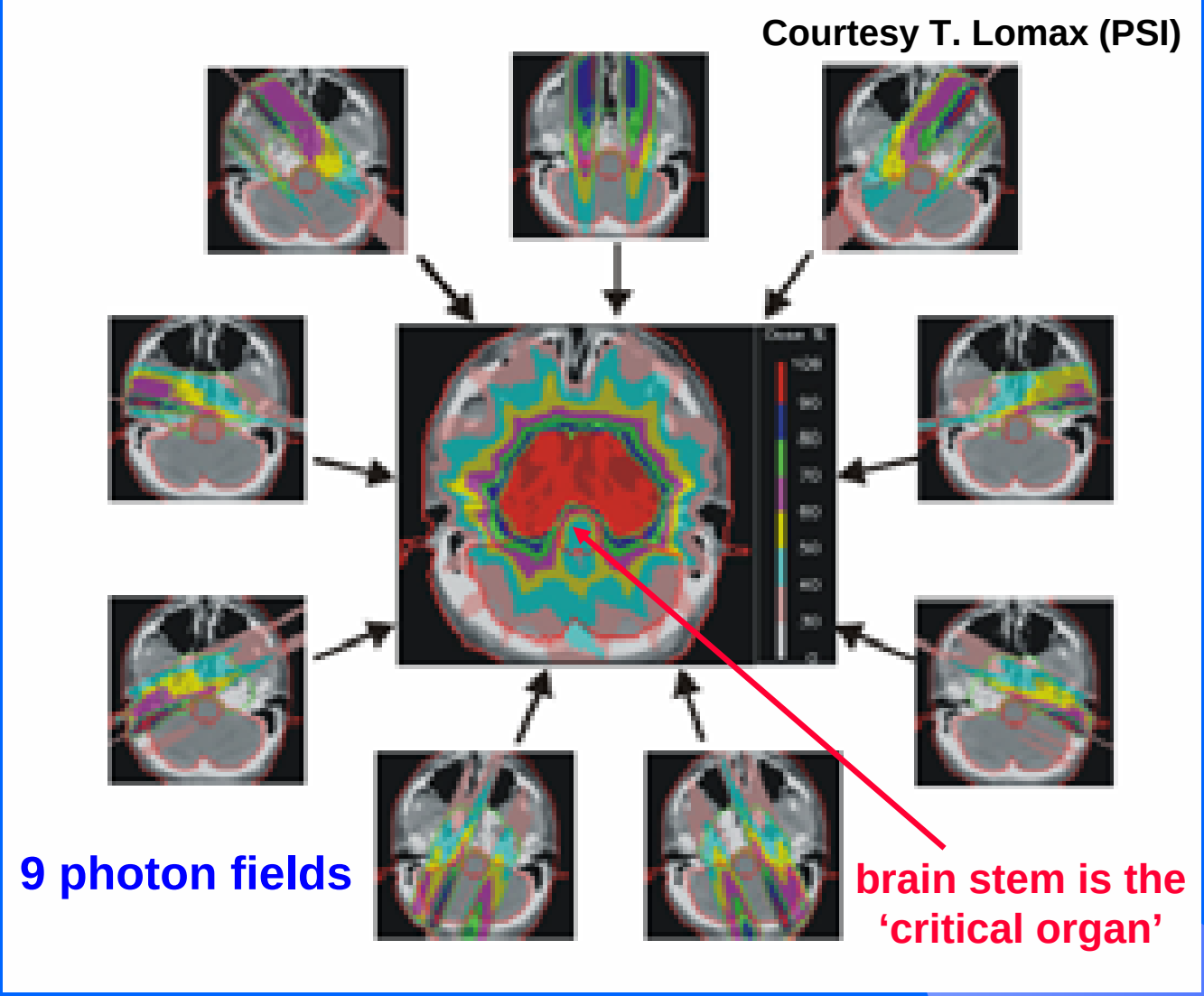
‘Conventional’ radiotherapy: linear accelerators dominate



In the world radiation oncologists use 10 000 electron linacs

40% of all the existing accelerators

Last 10 years: Intensity Modulated Radiation Therapy = IMRT…



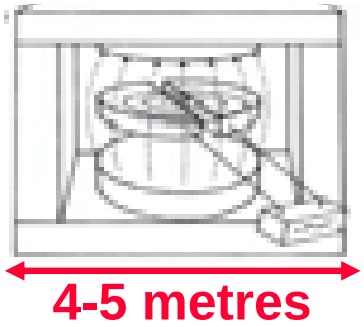
… and now "Image Guided Radio Therapy" for organ motion

Accelerators for protontherapy

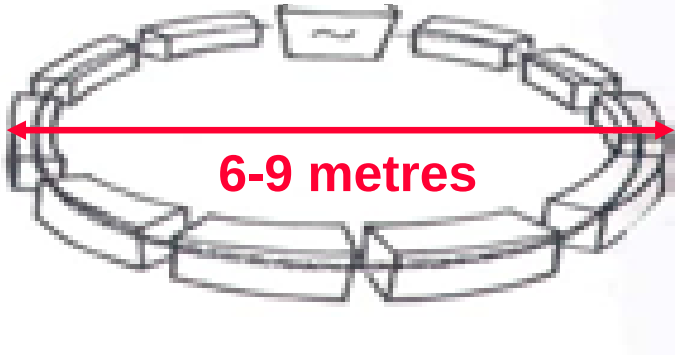
The accelerators used today in hadrontherapy are "circular"

Teletherapy with protons (200-250 MeV)

CYCLOTRONS (*) (Normal or SC)



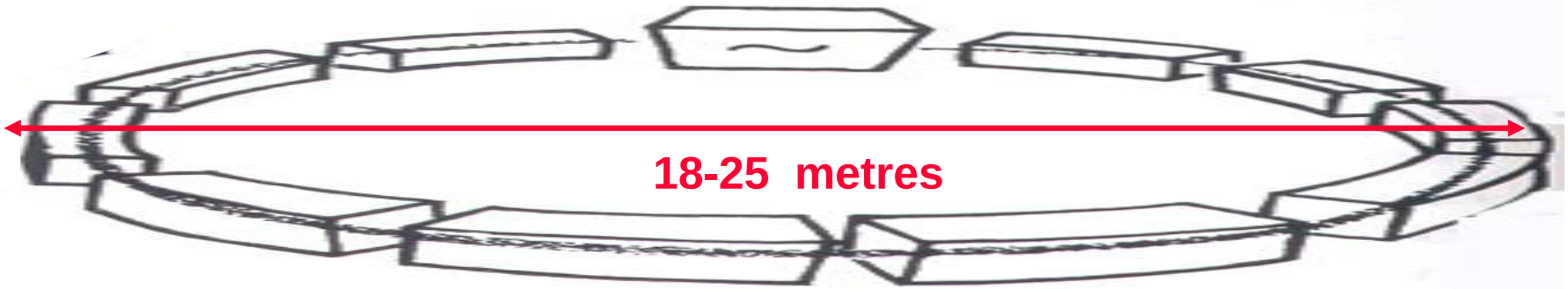
SYNCHROTRONS



(*) also synchrocyclotrons

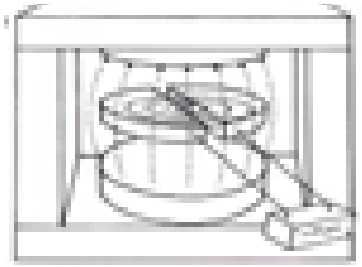
Teletherapy with carbon ions (4800 MeV = 400 MeV/u)

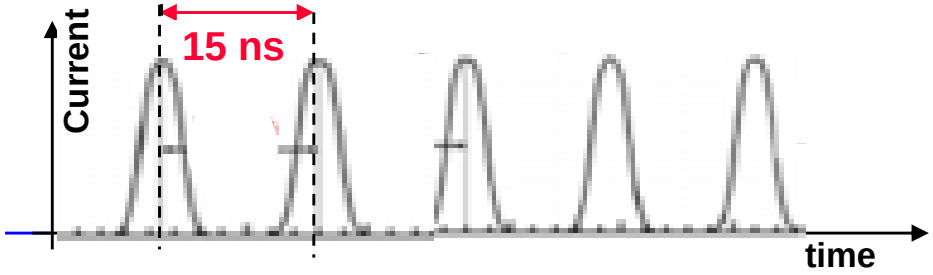
SYNCHROTRONS



The time structures of the beams are very different

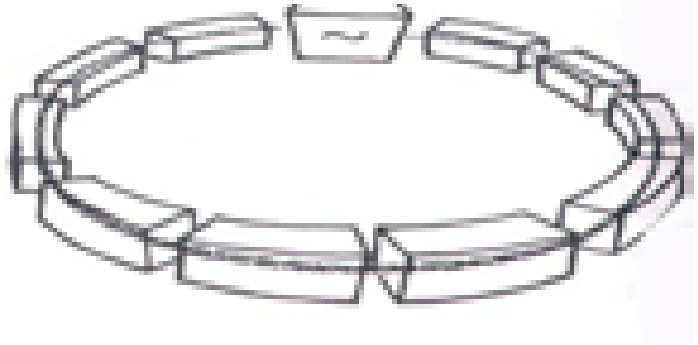
CYCLOTRONS (*) (Normal or SC)

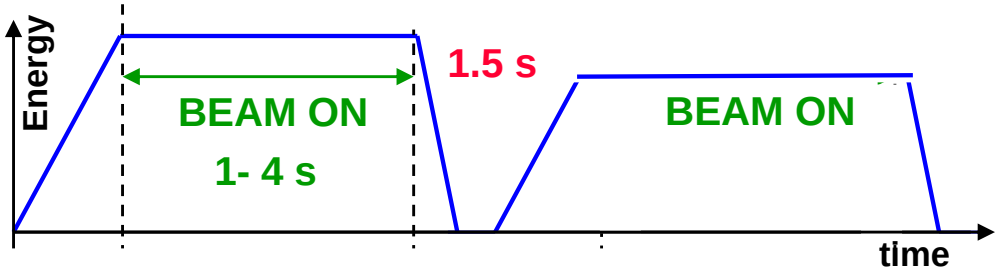




The pulsed beam of fixed energy is always present

SYNCHROTRONS





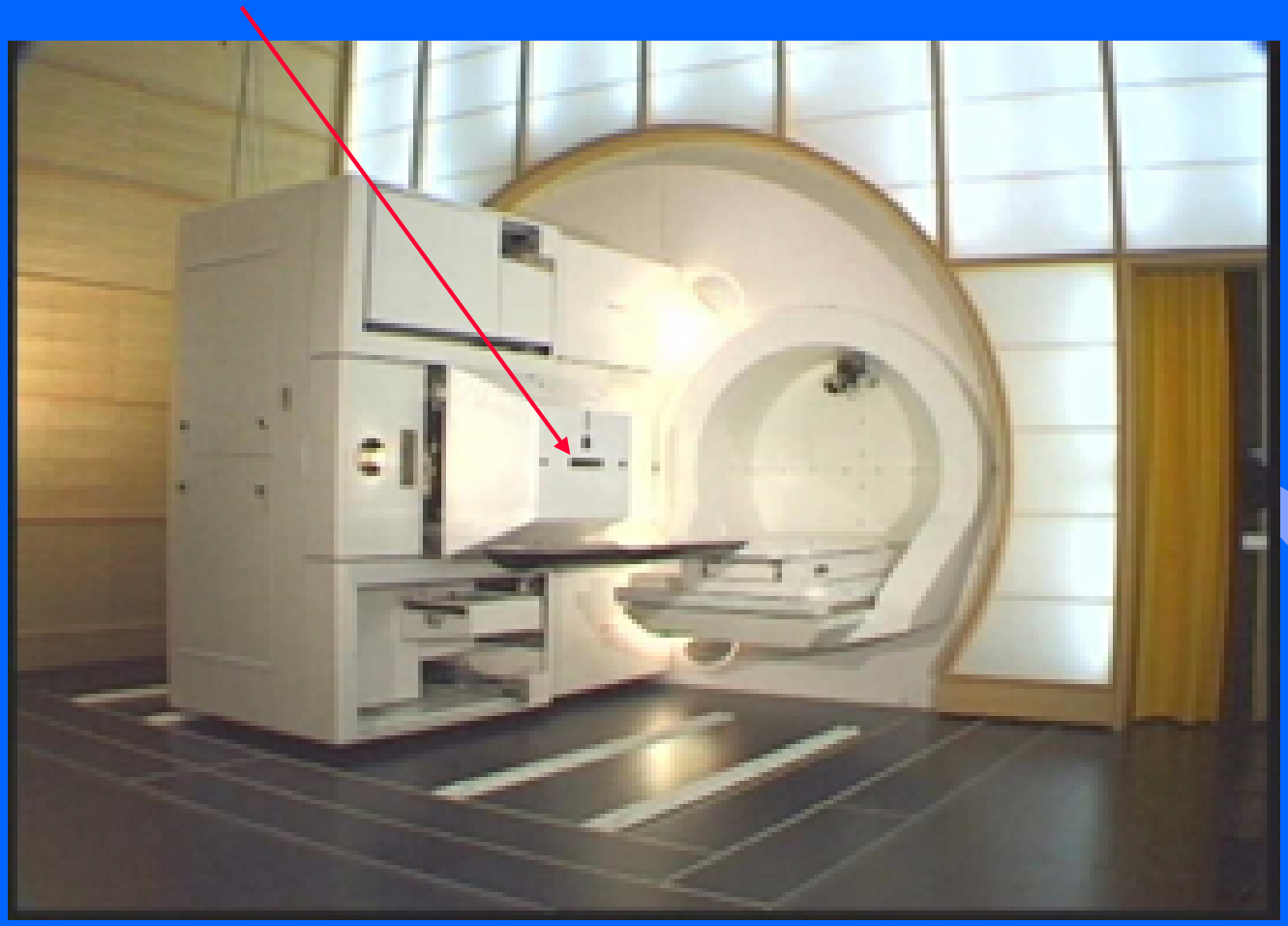
A cycling beam of variable energy has 1 second gaps

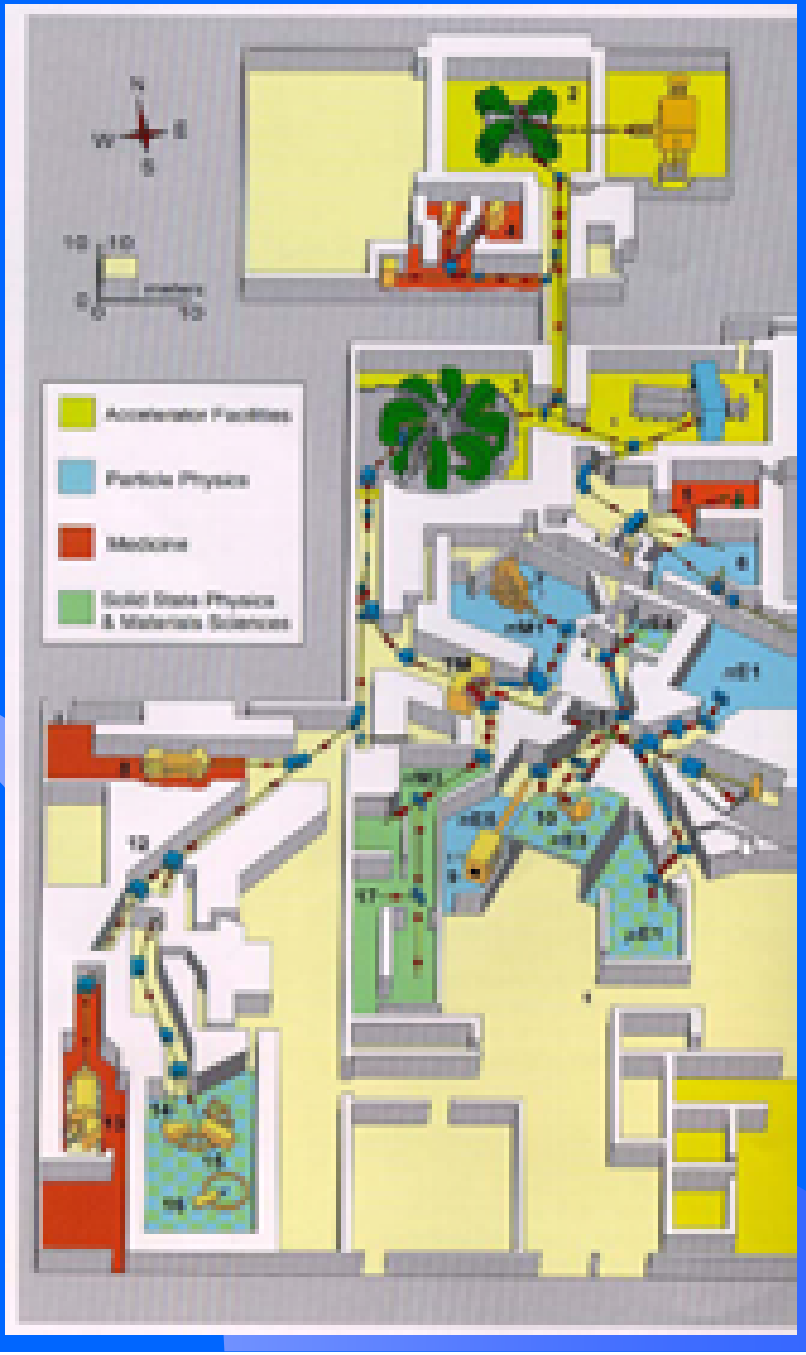
(*) A synchrocyclotrons cycles at hundreds Hertz

European succes story : 'spot scanning' with protons

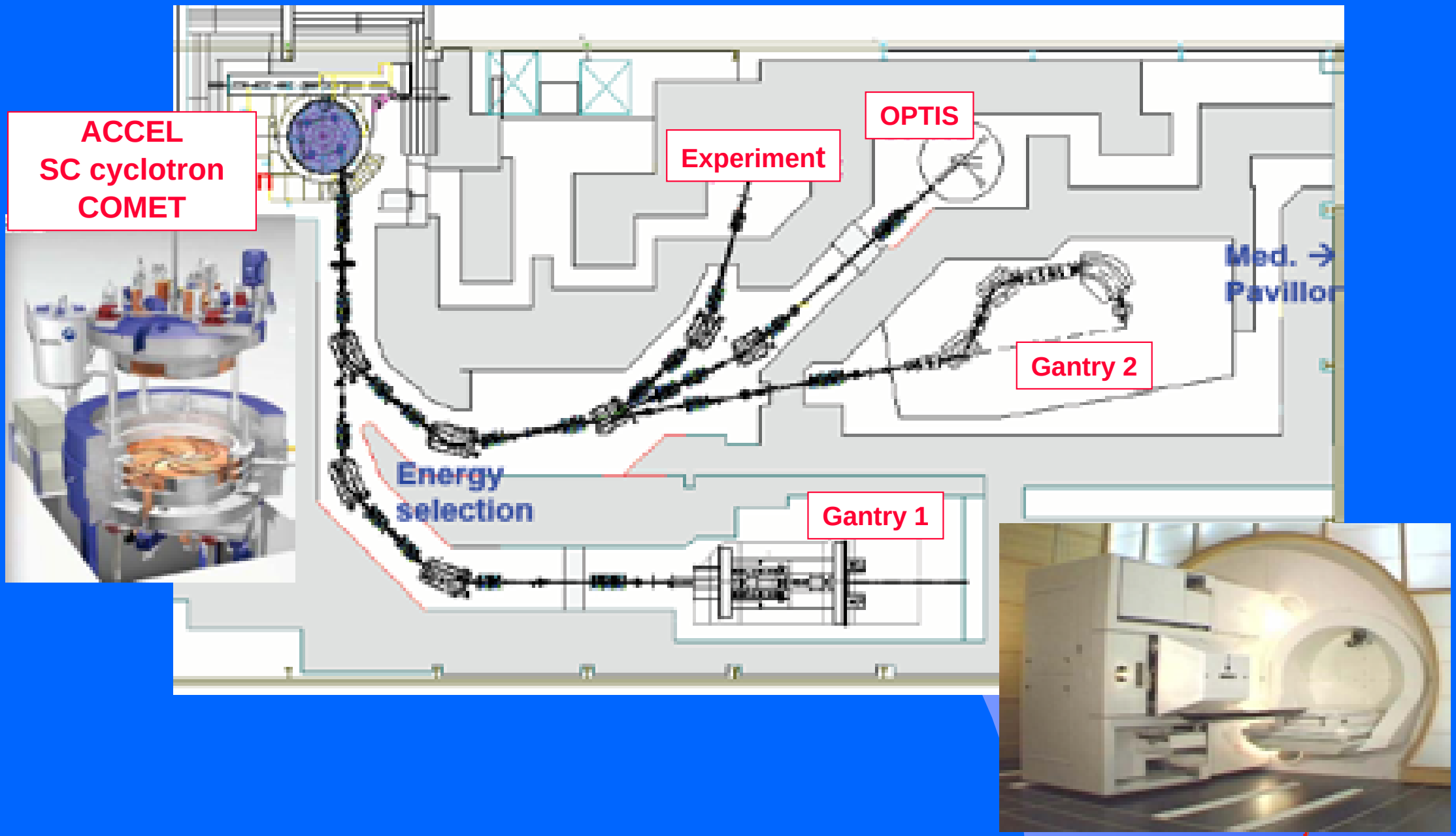
PSI (Villigen- Switzerland)

Gantry 1: 350 patients

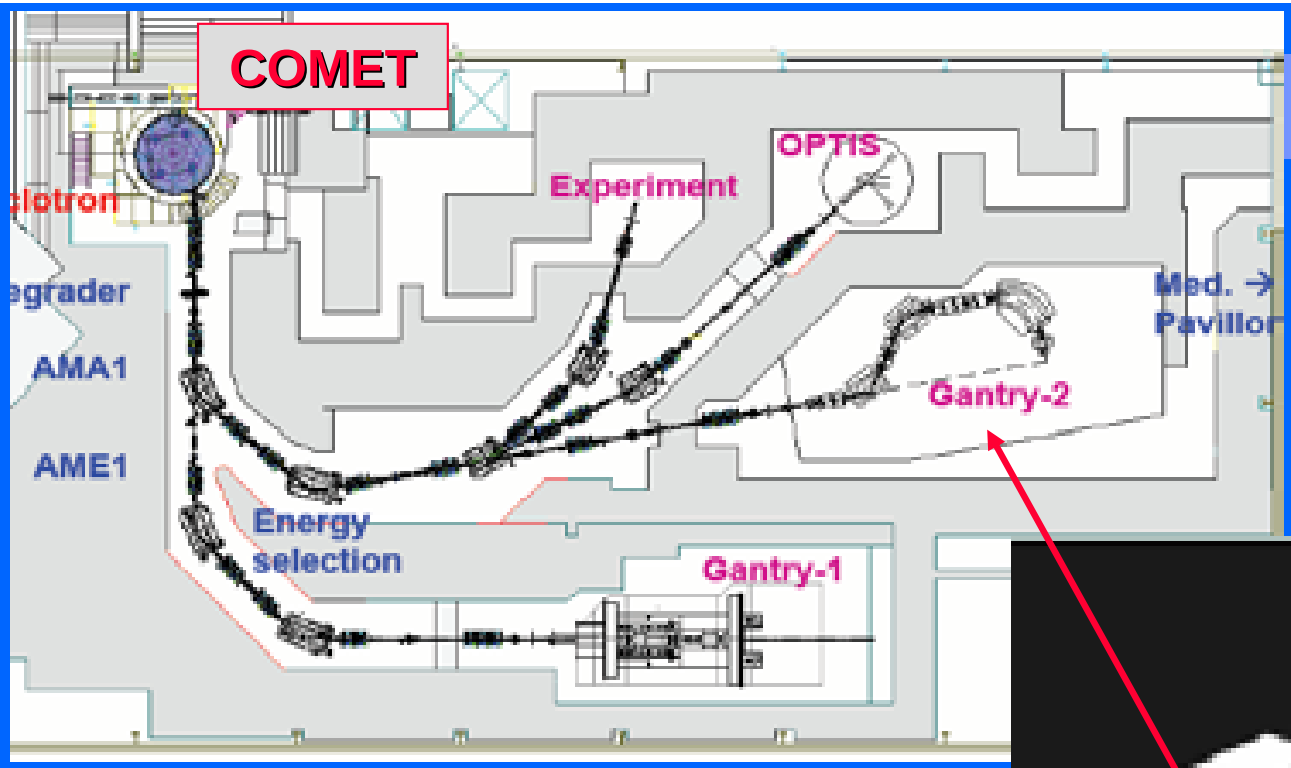


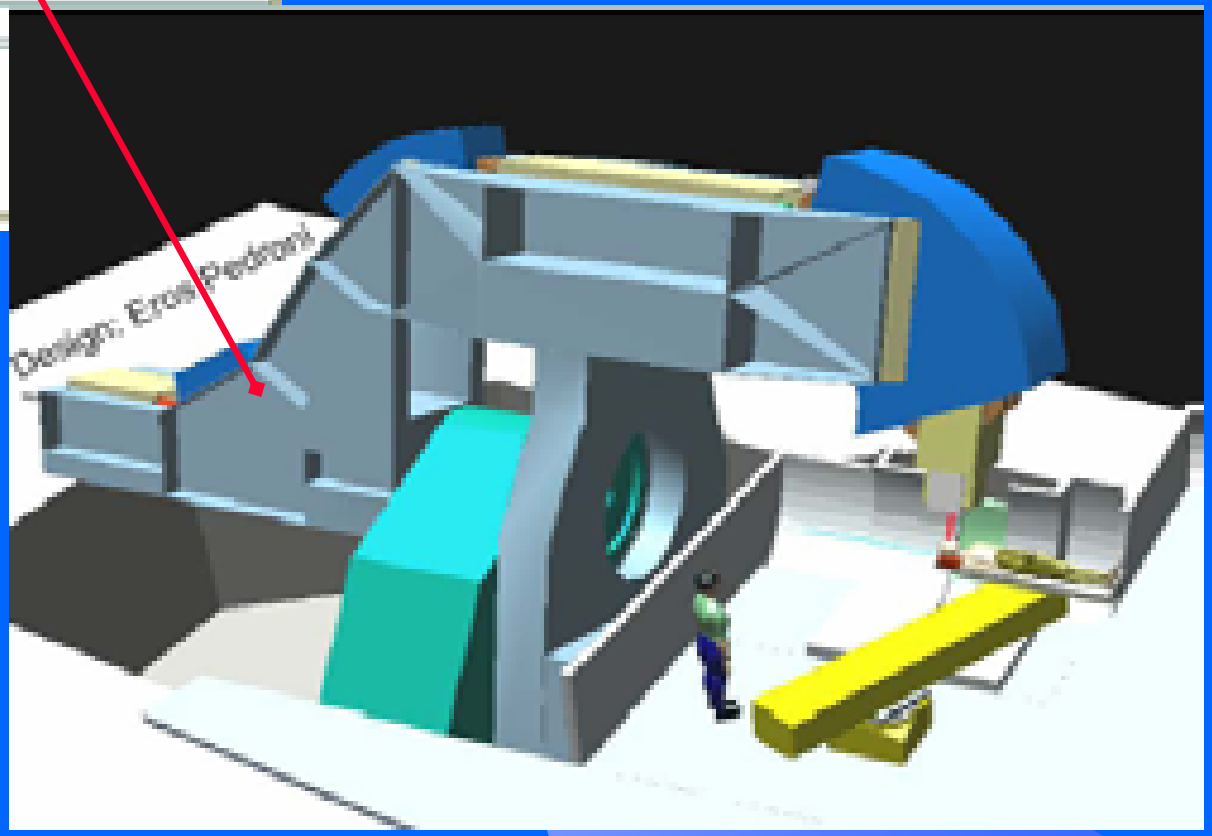


The PROSCAN project of PSI: 2007



The Gantry 2 of PSI: 2008





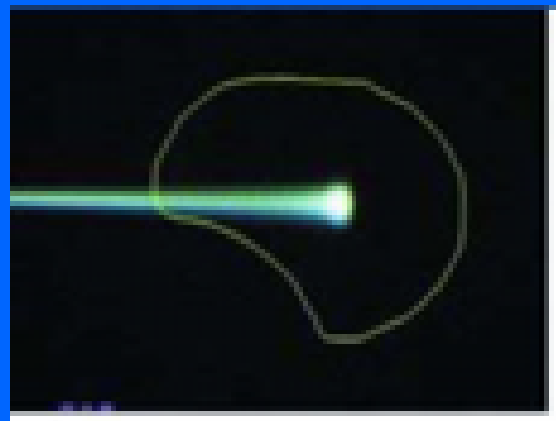
Compact design: 3.5 m radius

Rotation on one side only

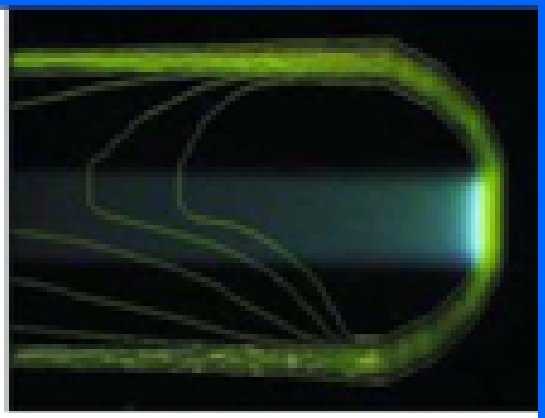
Double parallel scanning

<u>Spot scanning technique</u>

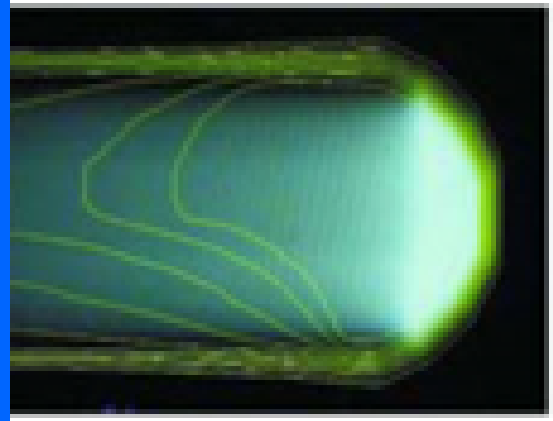
Spot scanning at PSI with Gantry 2



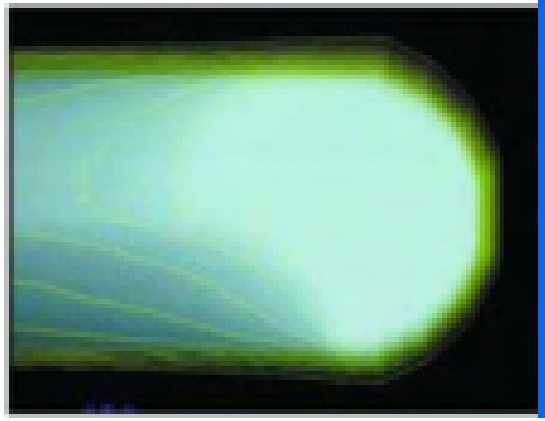
Single ‘spot’



1. Lateral scanning with bending magnet upstream at 2 ms/step



2. Depth scanning by changing energy with absorber upstream

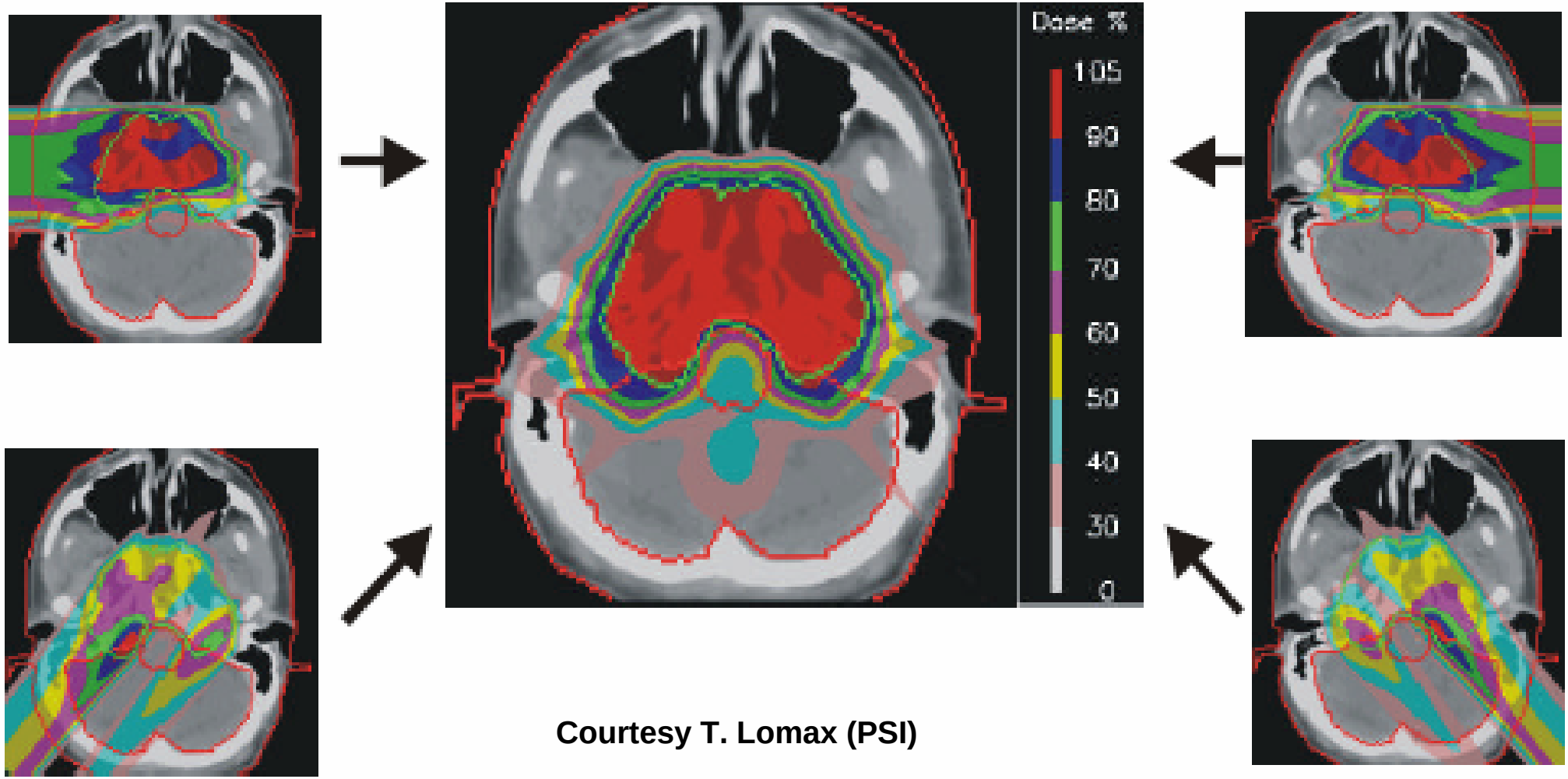


3. Lateral scanning with bending magnet and moving the bed

In future: fast beam scanning with repainting

IMPT = Intensity Modulated Particle Therapy with protons

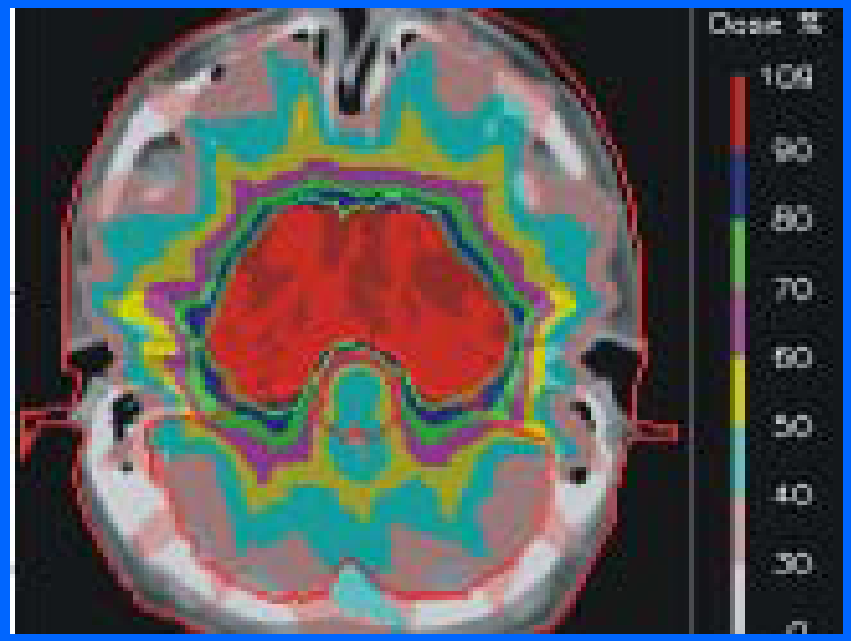
4 NON-UNIFORM FIELDS



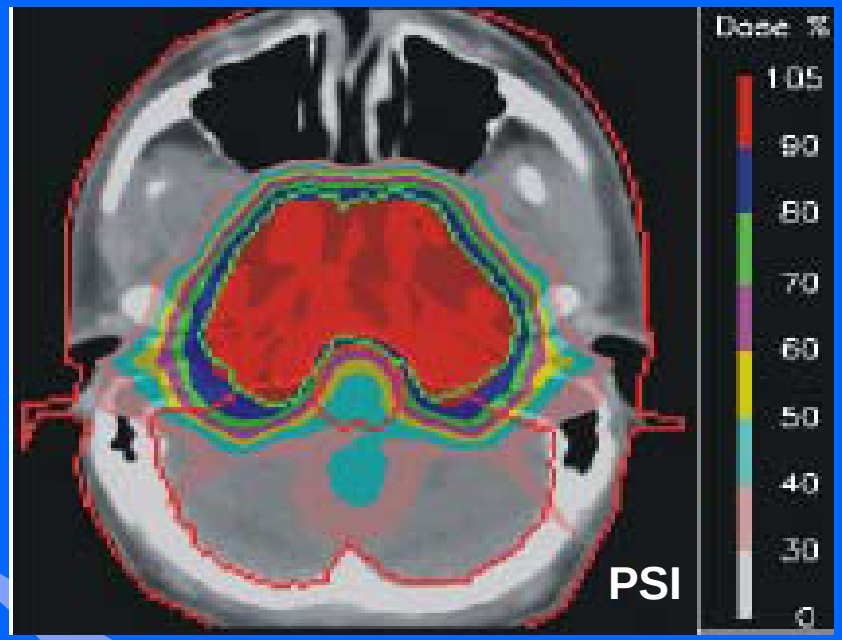
Courtesy T. Lomax (PSI)

Protons are quantitatively different from X-rays

9 X-ray fields

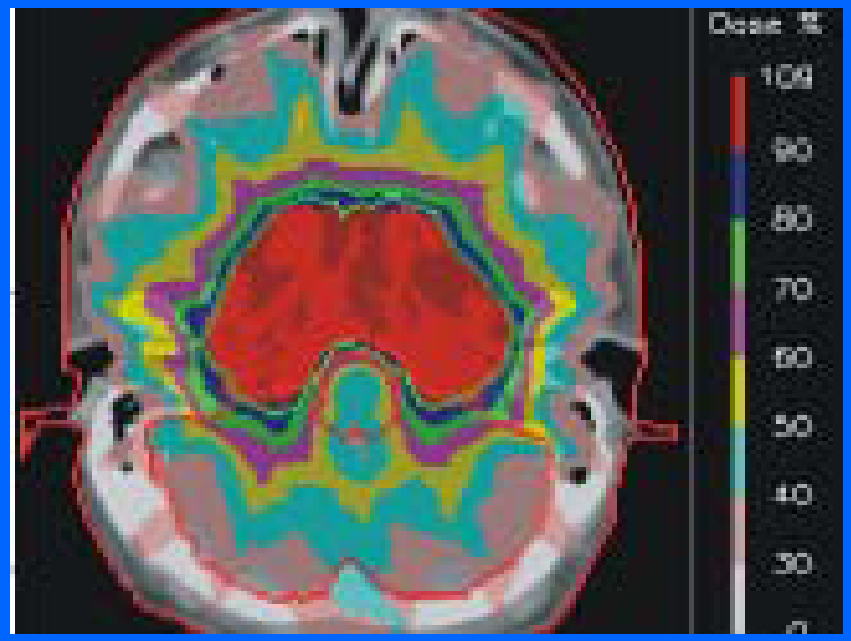


4 proton fields

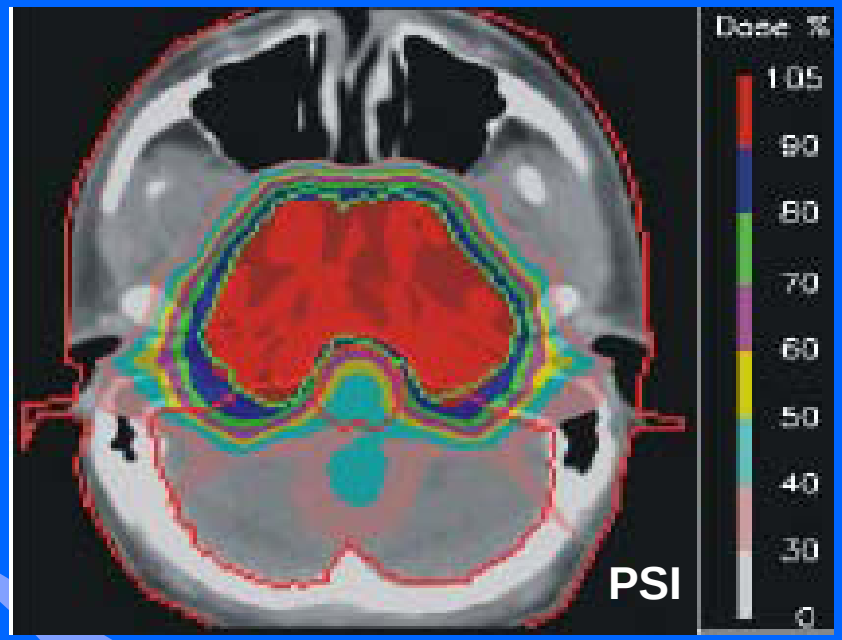


Protons are quantitatively different from X-rays

9 X-ray fields



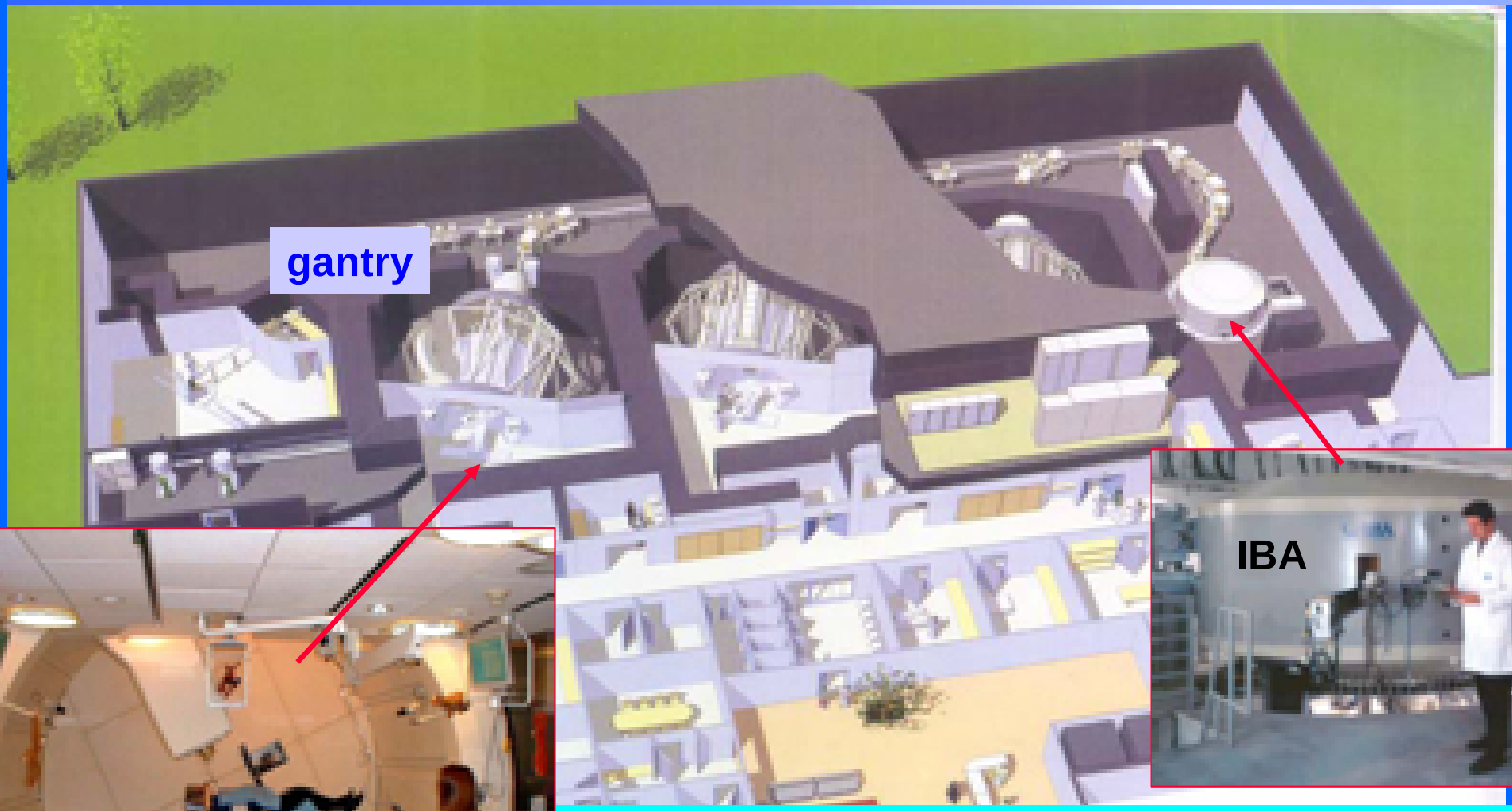
4 proton fields



Carbon ions deposit in a cell 24 times more energy than a proton producing not reparable damages

Carbon ions are qualitatively different from X rays and can control radioresistant tumours

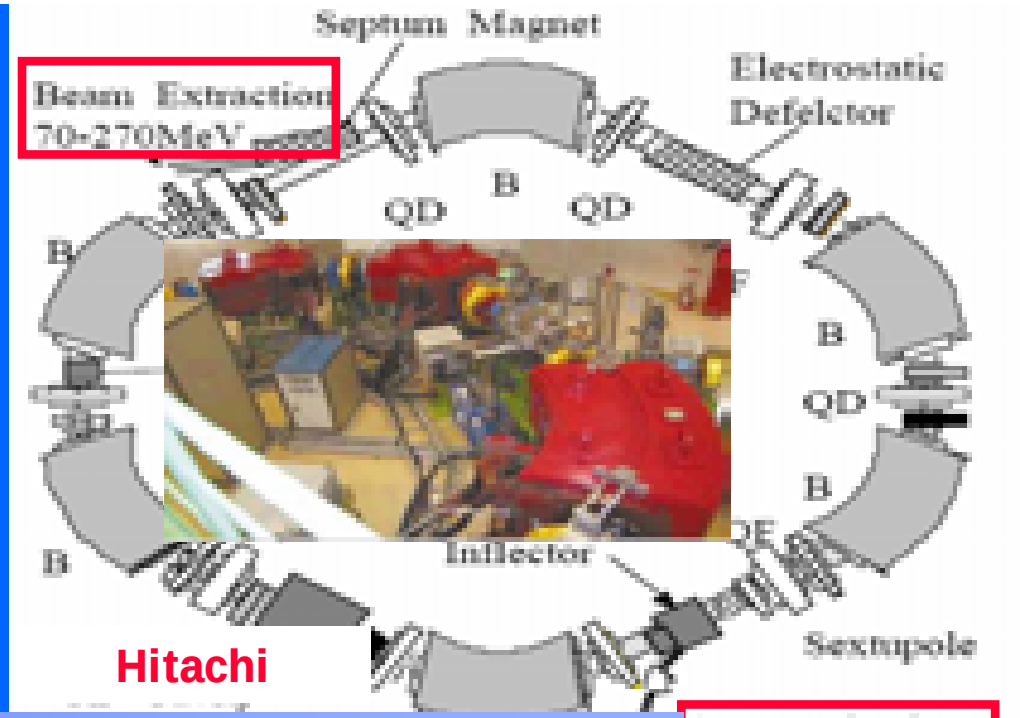
Commercial cyclotron solution for protons by IBA - Belgium



Five companies offer turn-key centres for 80-100 M€.

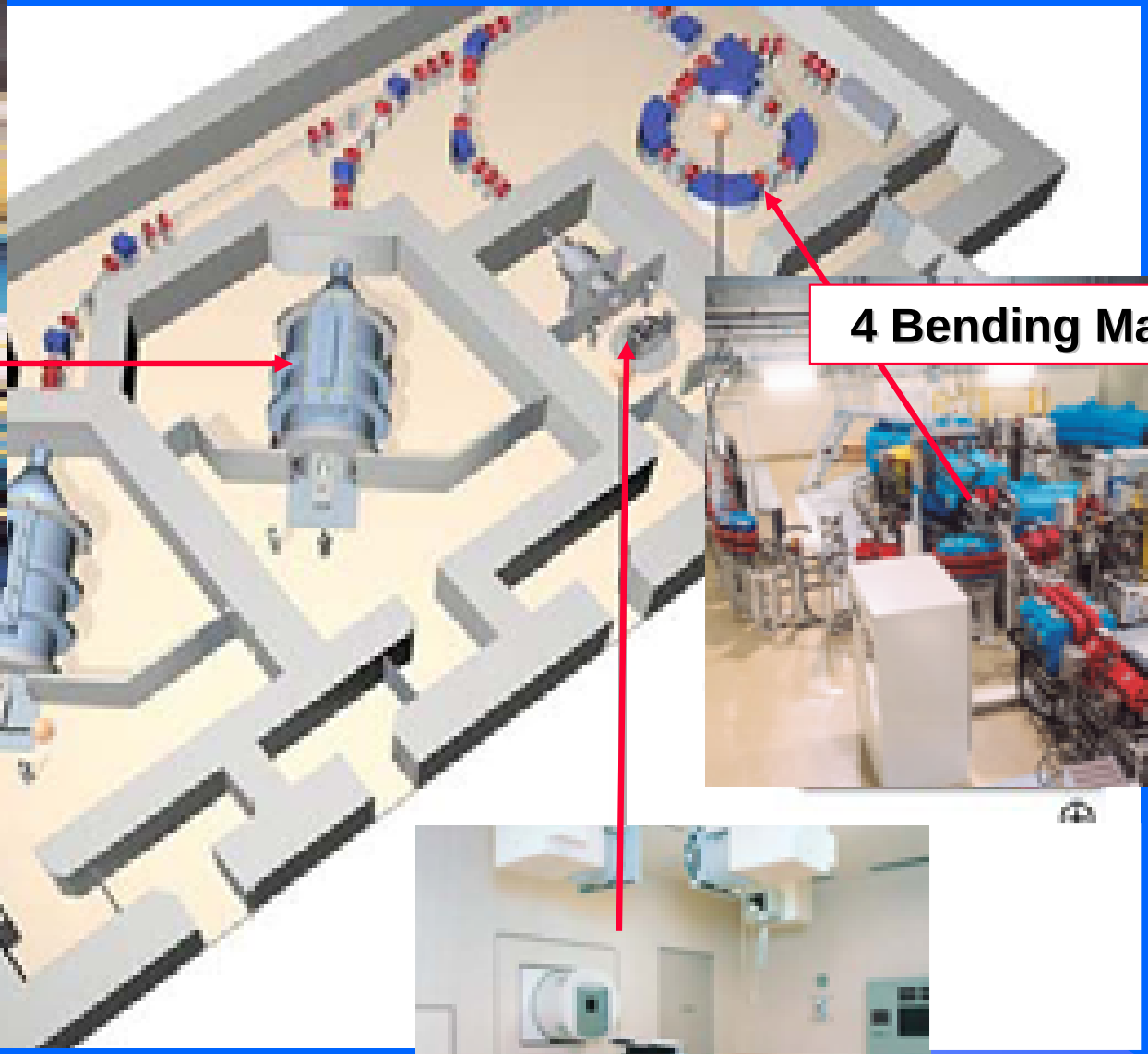
If proton accelerators were 'small' and 'cheap', no radiotherapist would use X rays.

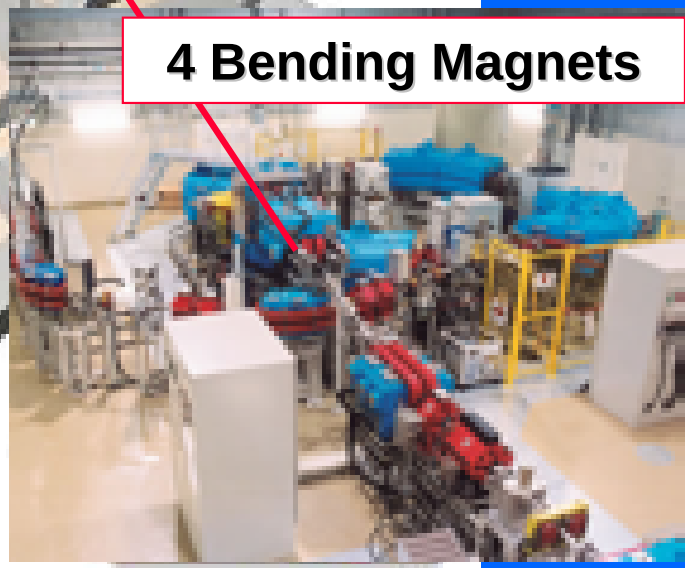
Cyclotrons need a long ESS to reduce the energy



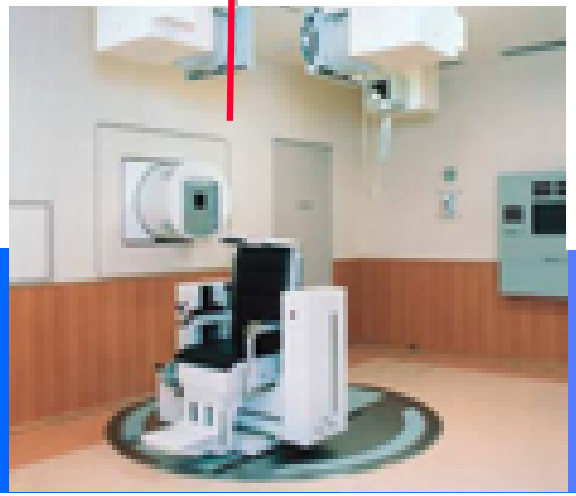
Protontherapy: a mature market…

Mitsubishi solution for Shizuoka - Japan

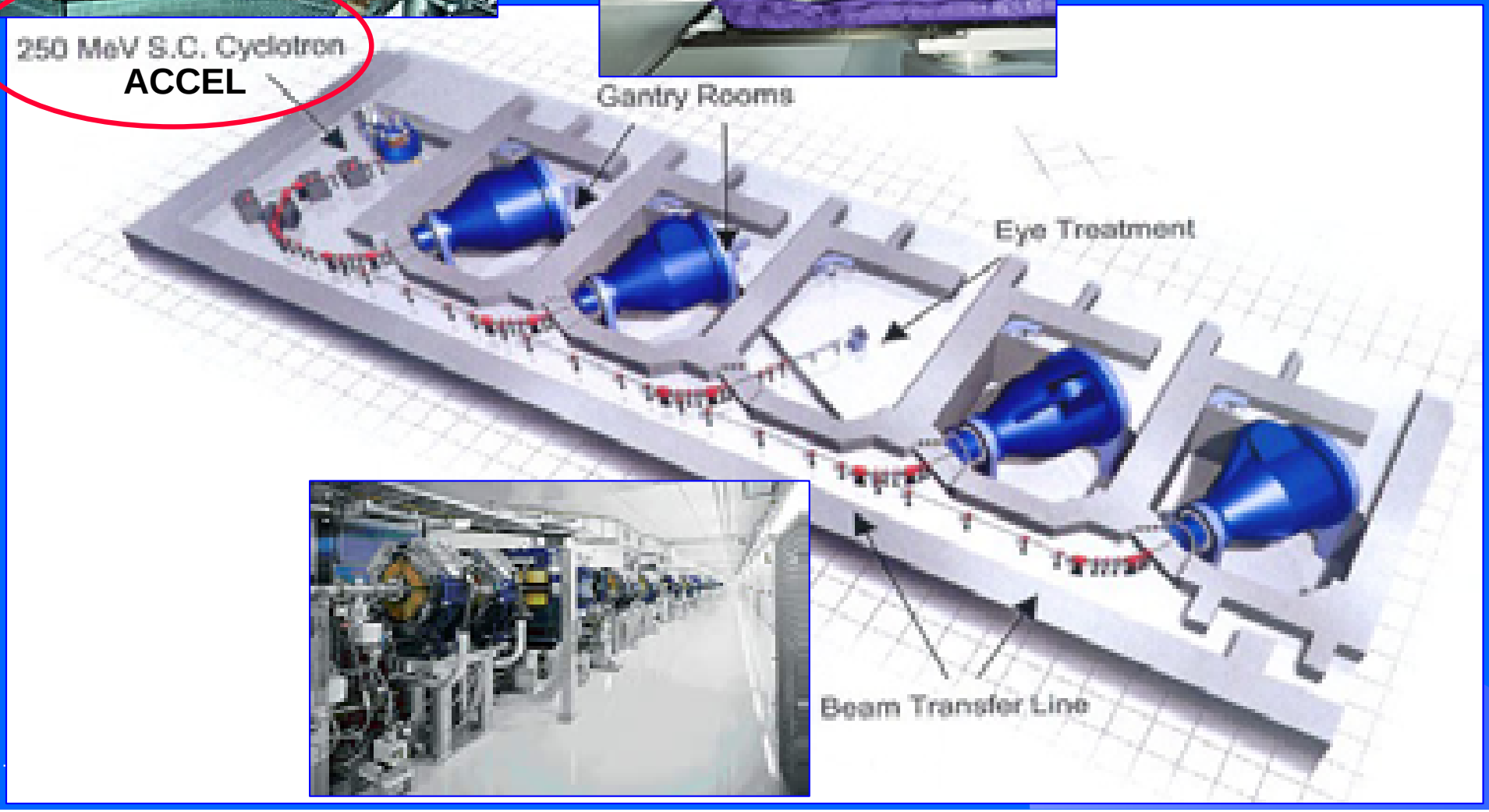




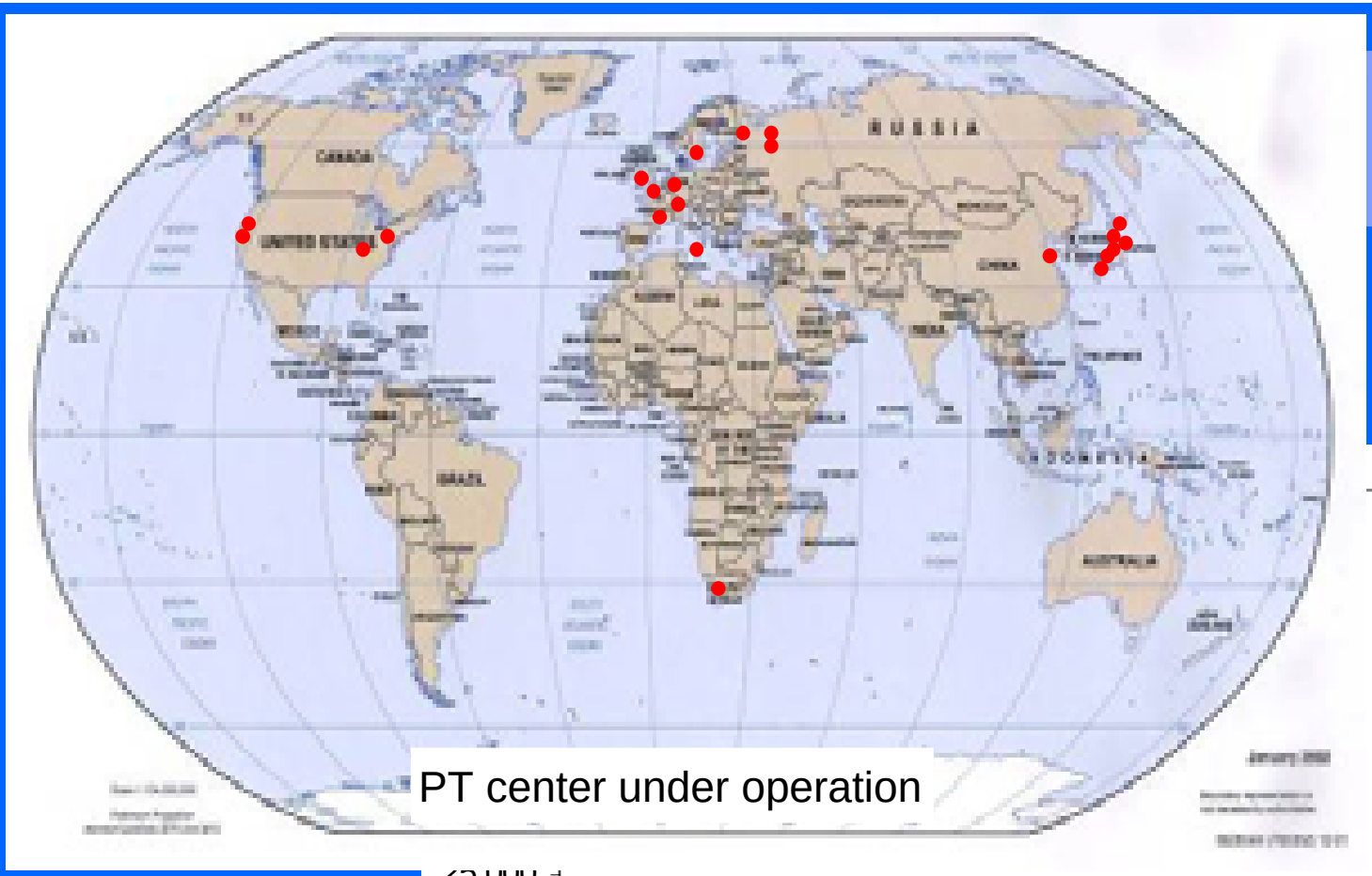
4 Bending Magnets

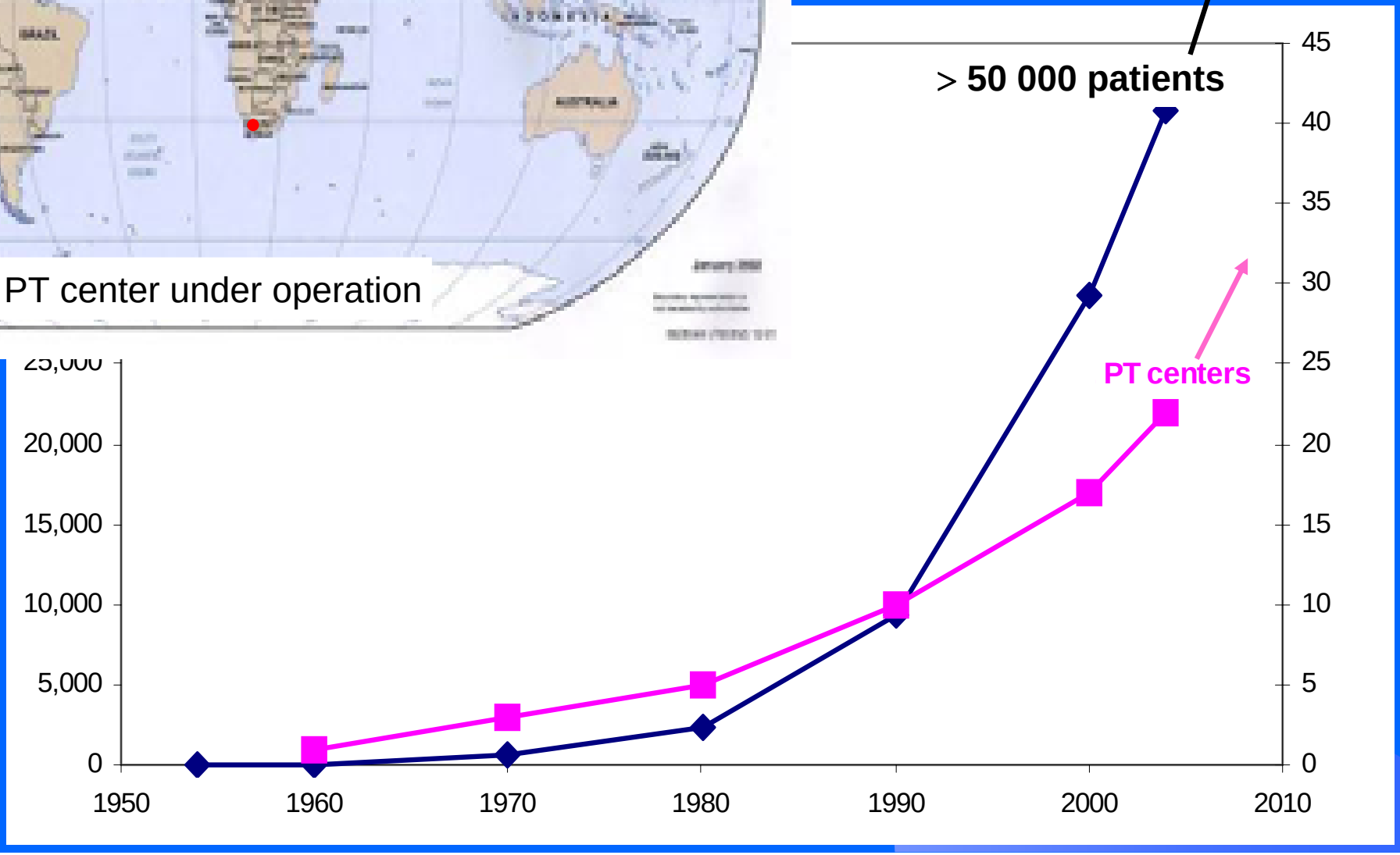


Rinecker Proton Therapy Centre Munich



Protontherapy is booming



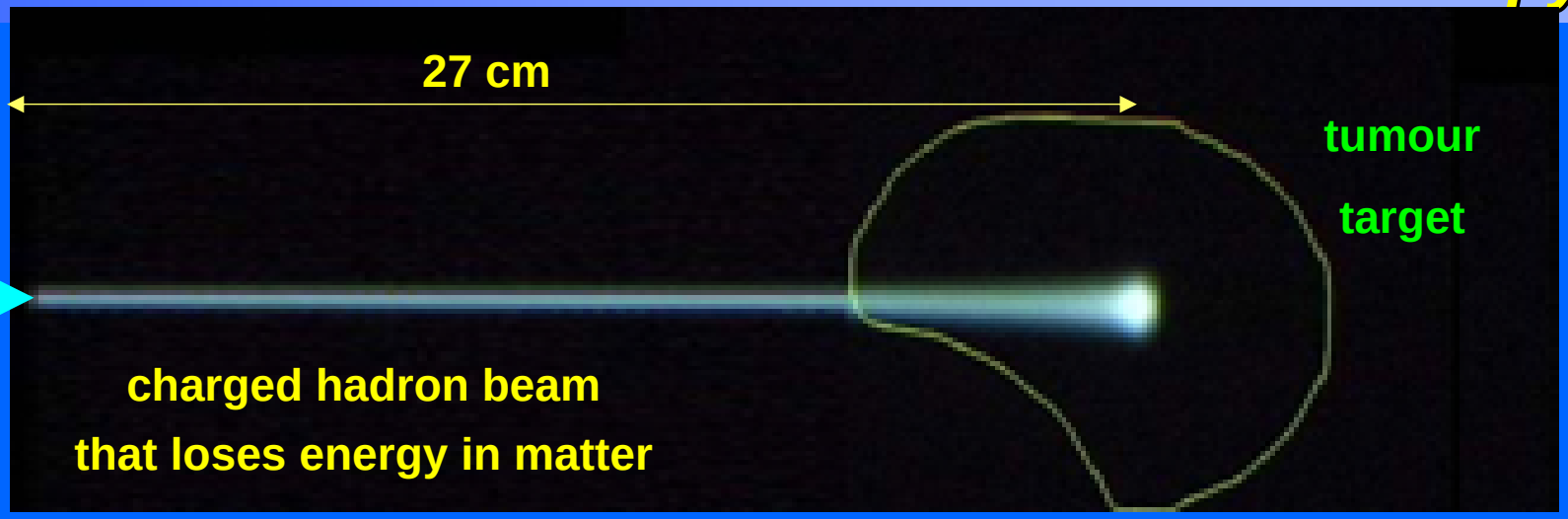


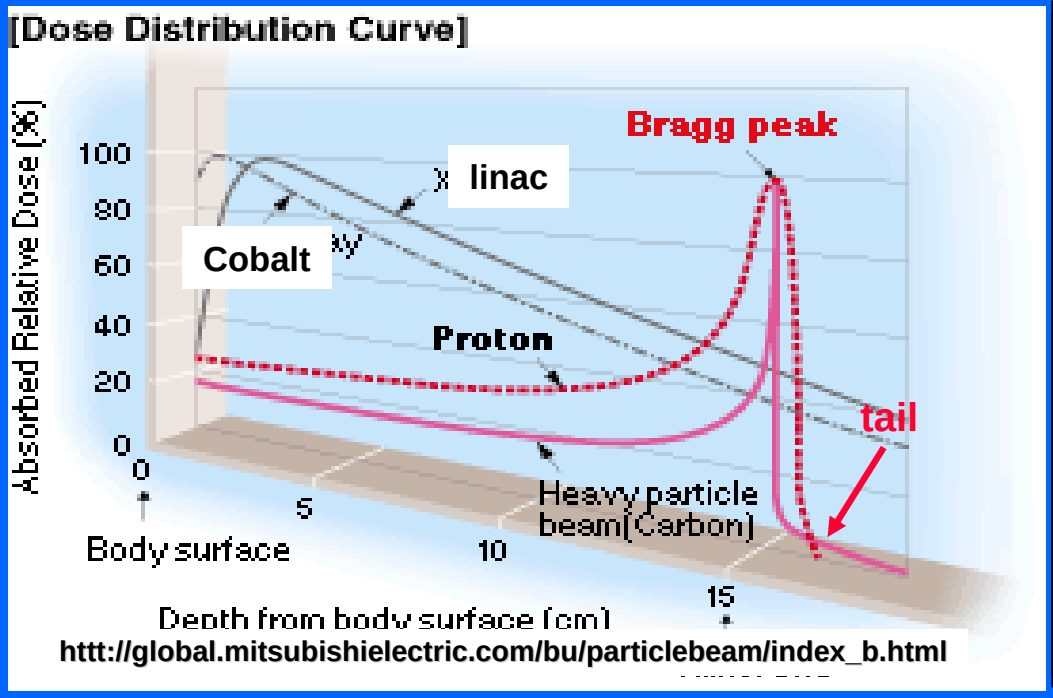
Accelerators for carbon therapy

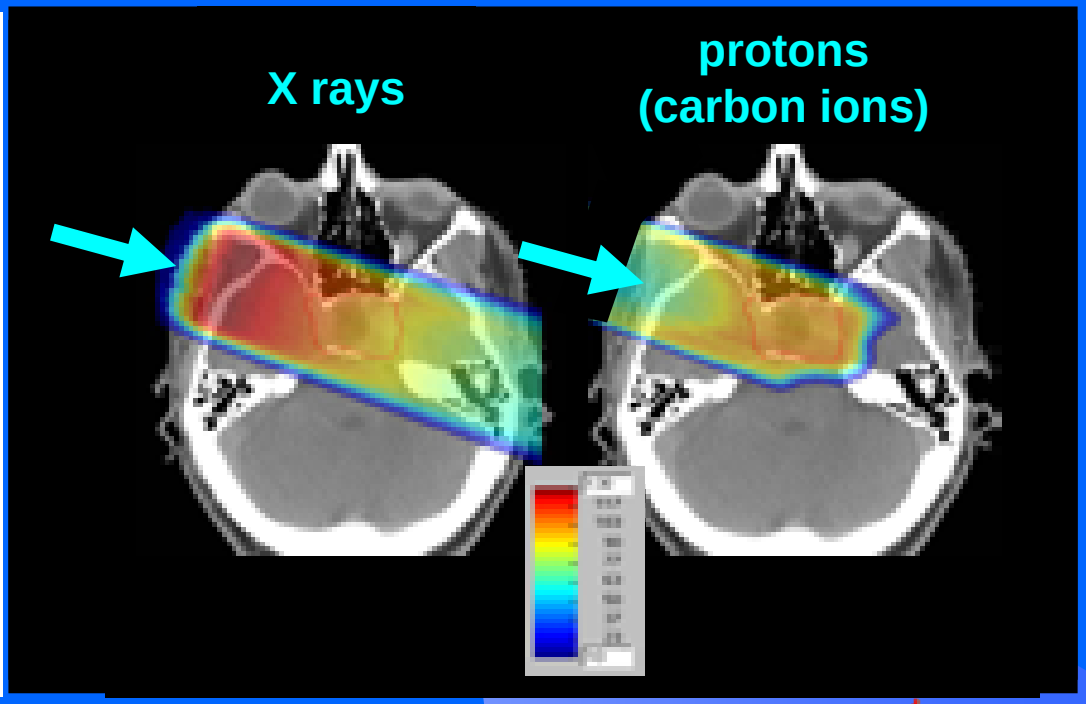
The foundations of hadrontherapy

200 MeV
Protons
but only 1 nA

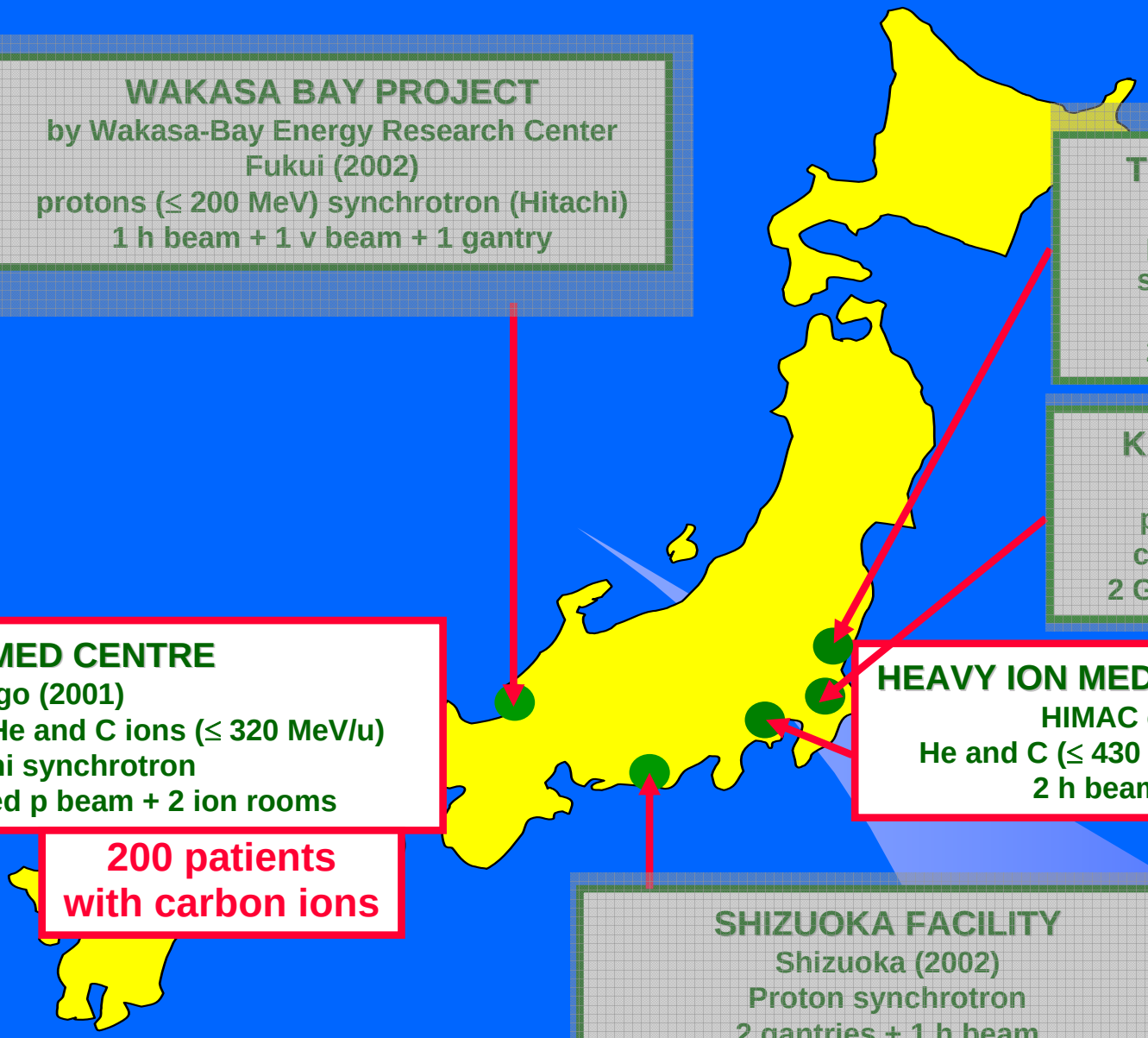
4800 MeV
carbon ions
but only 0.1 nAe







Japan: 4 proton and 2 carbon ion centres



WAKASA BAY PROJECT
by Wakasa-Bay Energy Research Center
Fukui (2002)
protons (≤ 200 MeV) synchrotron (Hitachi)
1 h beam + 1 v beam + 1 gantry

TSUKUBA CENTRE
Ibaraki (2001)
protons (≤ 270 MeV)
synchrotron (Hitachi)
2 gantries
2 beam for research

KASHIWA CENTER
Chiba (1998)
protons (≤ 235 MeV)
cyclotron (IBA – SHI)
2 Gantries + 1 hor. beam

HYOGO MED CENTRE
Hyogo (2001)
protons (≤ 230 MeV) - He and C ions (≤ 320 MeV/u)
Mitsubishi synchrotron
2 p gantries + 2 fixed p beam + 2 ion rooms

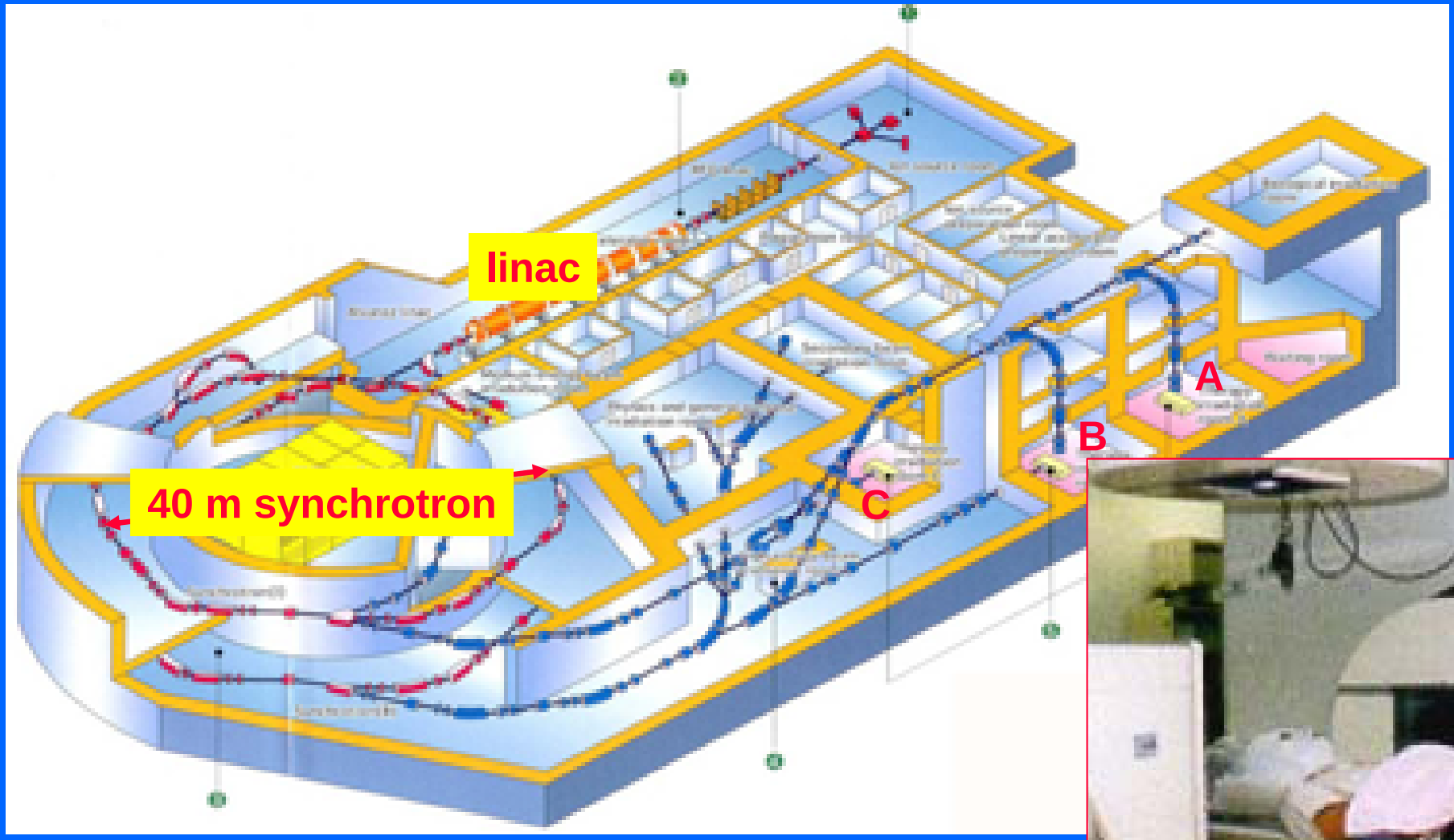
200 patients with carbon ions

HEAVY ION MEDICAL ACCELERATOR
HIMAC of NIRS (1995)
He and C (≤ 430 MeV/u) 2 synchrotrons
2 h beams + 2 v beams

4000 patients with carbon ions

SHIZUOKA FACILITY
Shizuoka (2002)
Proton synchrotron
2 gantries + 1 h beam

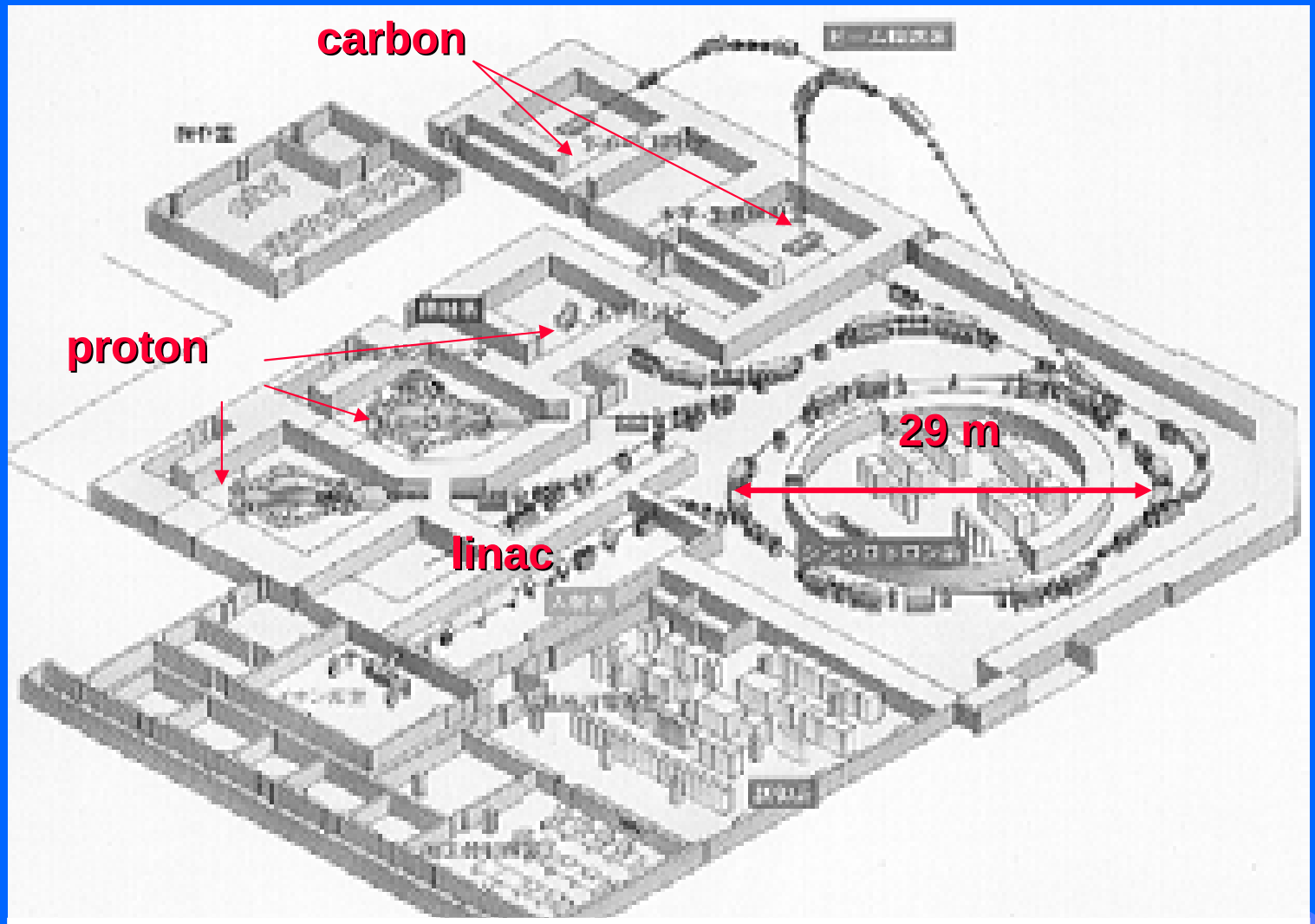
HIMAC (Japan) pioners carbon therapy



4000 patients

No repair mechanism: 6-9 sessions only

The Hyogo 'dual' Centre



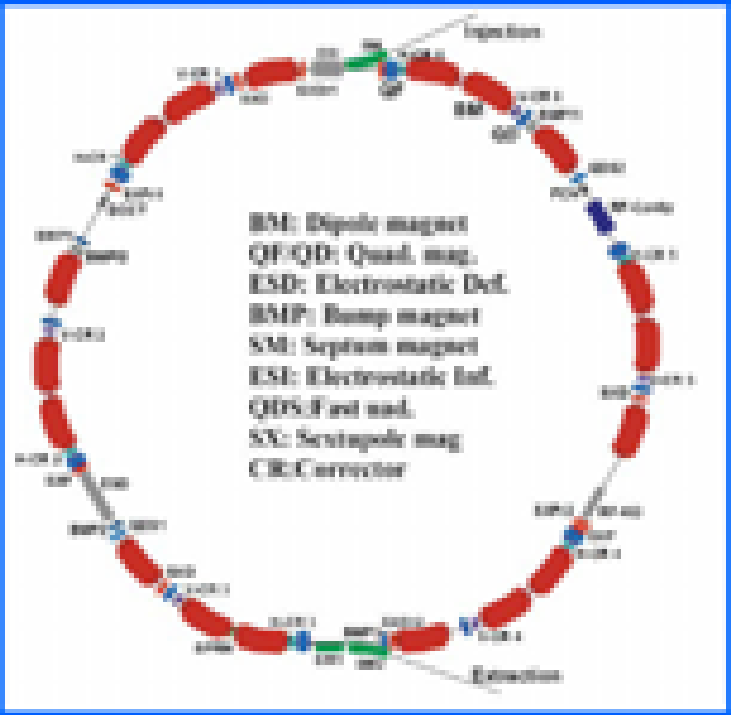
Mitsubishi: turn-key system

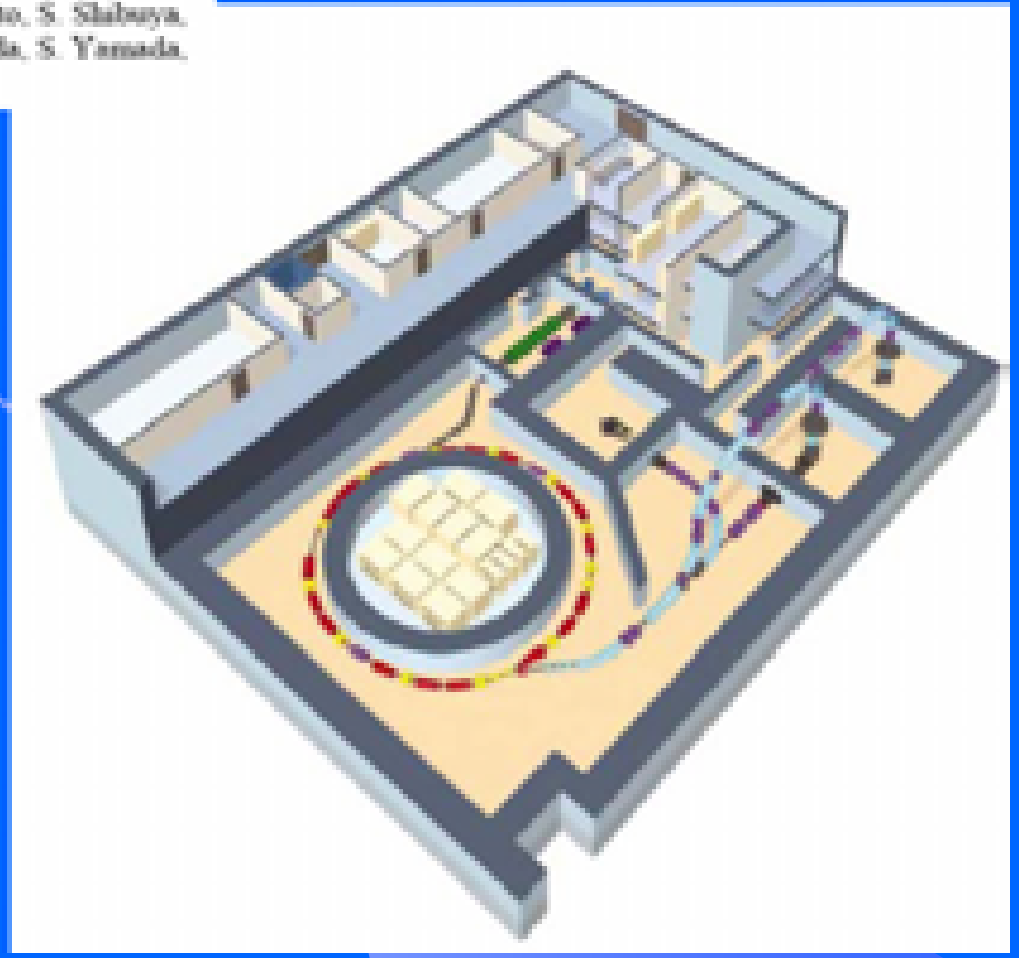
The ‘dual’ centre of the Gunma University is in construction

Proceedings of APAC 2004, Gyeongju, Korea

HIMAC AND NEW FACILITY DESIGN FOR WIDE SPREAD USE OF CARBON CANCER THERAPY

K. Noda, T. Fujisawa, T. Furukawa, Y. Iwata, T. Kanai, M. Kanazawa, N. Kanematsu, A. Kitagawa, Y. Kobayashi, M. Komori, S. Minohara, T. Murakami, M. Muramatsu, S. Sato, Y. Sato, S. Shibuya, F. Soga, E. Takada, O. Takahashi, M. Torikoshi, T. H. Uesugi, E. Urakabe, K. Yoshida, S. Yamada,
National Institute of Radiological Sciences,



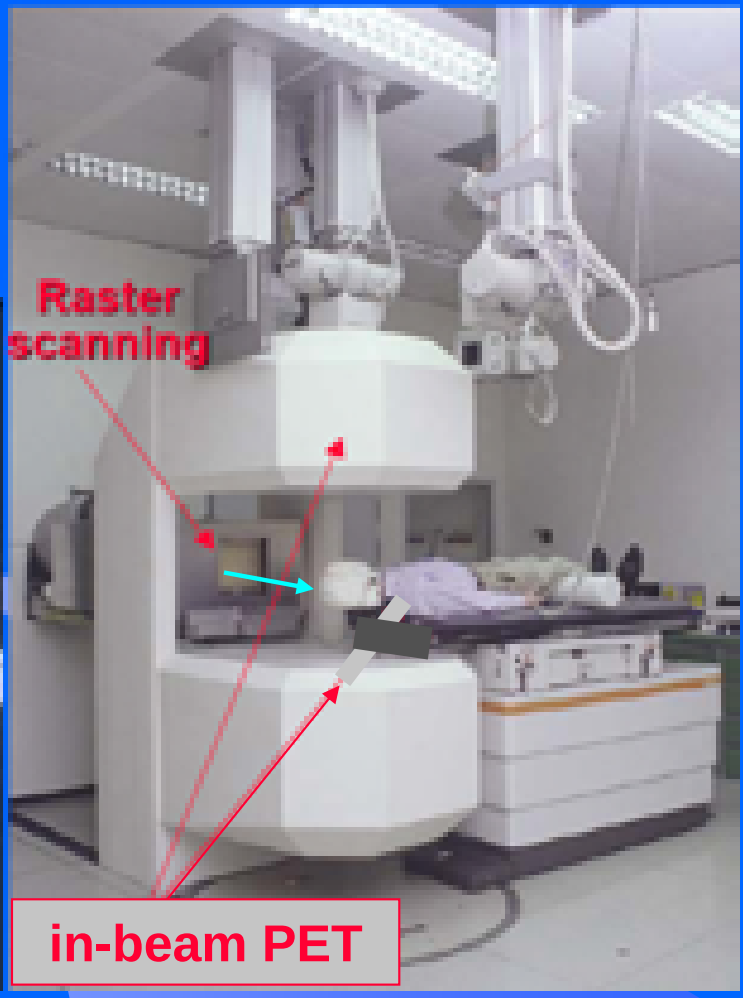


Second European success story: the Darmstadt GSI 'pilot project' (1997-2008)

G. Kraft

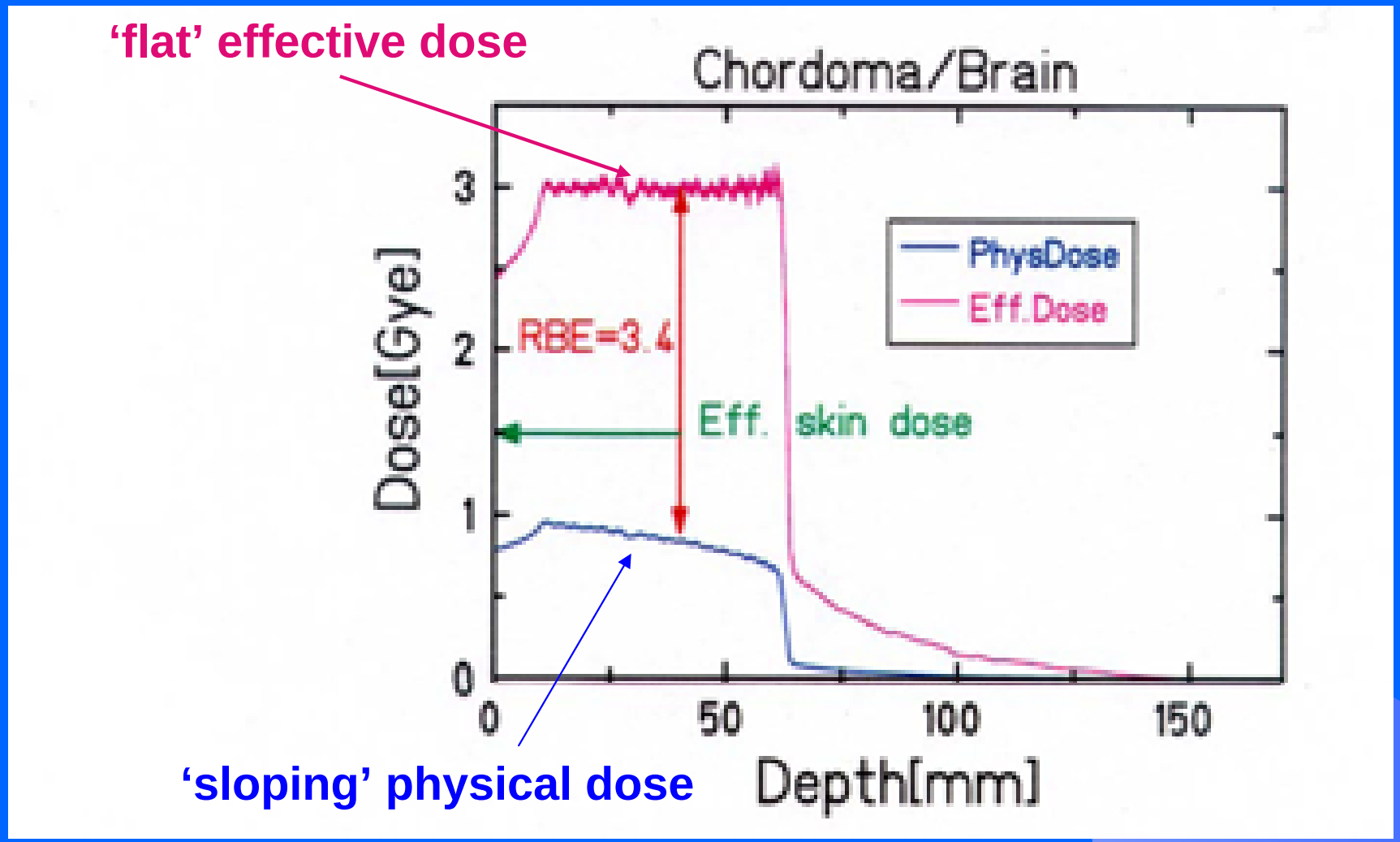
400 patients treated with carbon ions

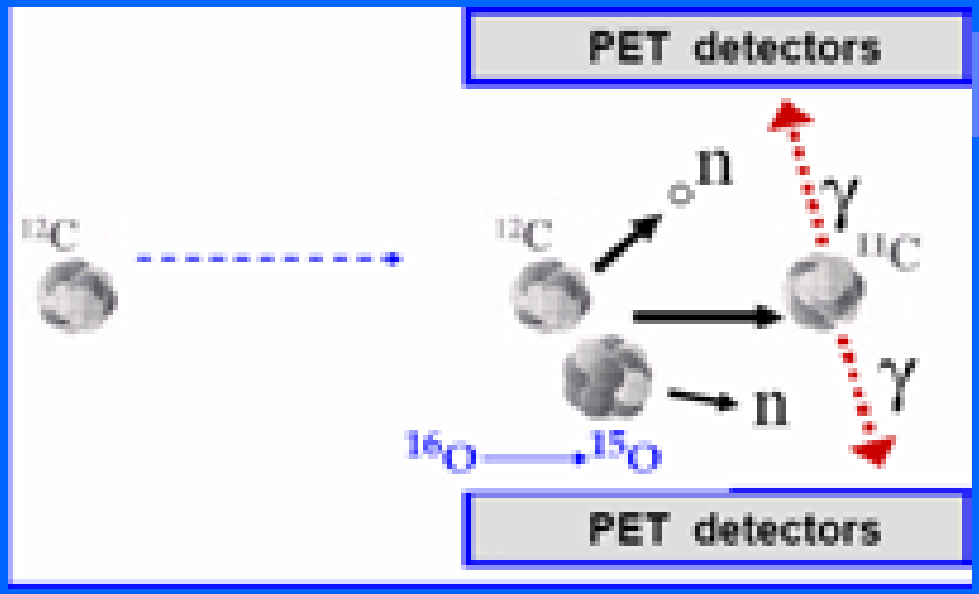
J. Debus (Heidelberg Univ.)



Local Effect Model for calculation of EBR in the Treatment Planning System (TPS)

The GSI model (G. Kraft, M. Scholz et al) allows the calculation of RBE point by point from the flux of the various ions

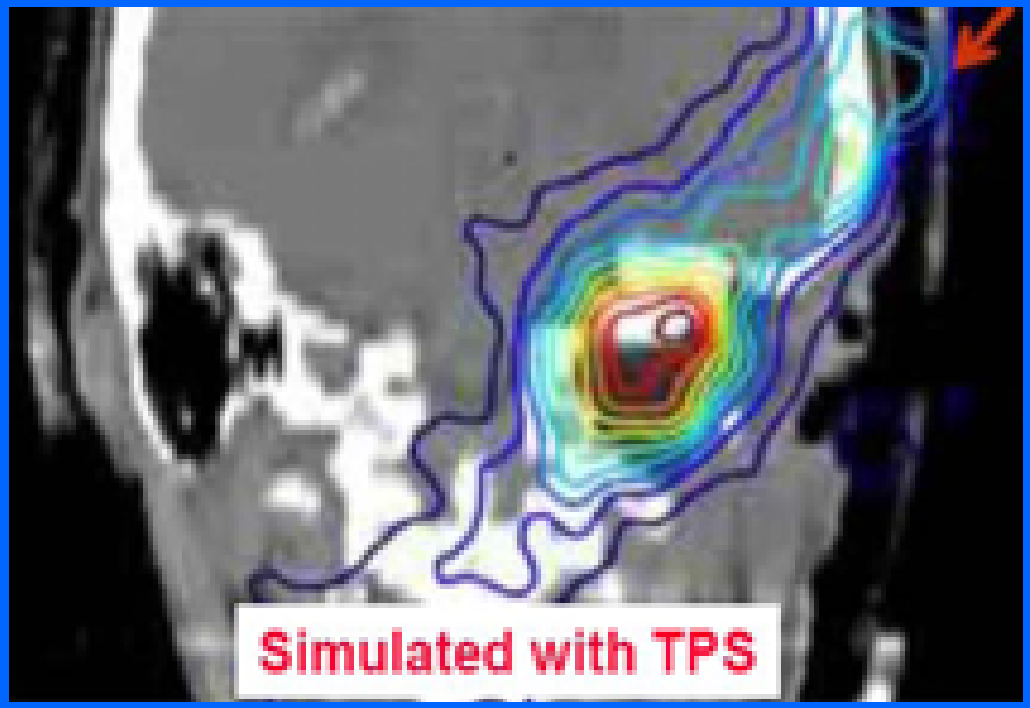


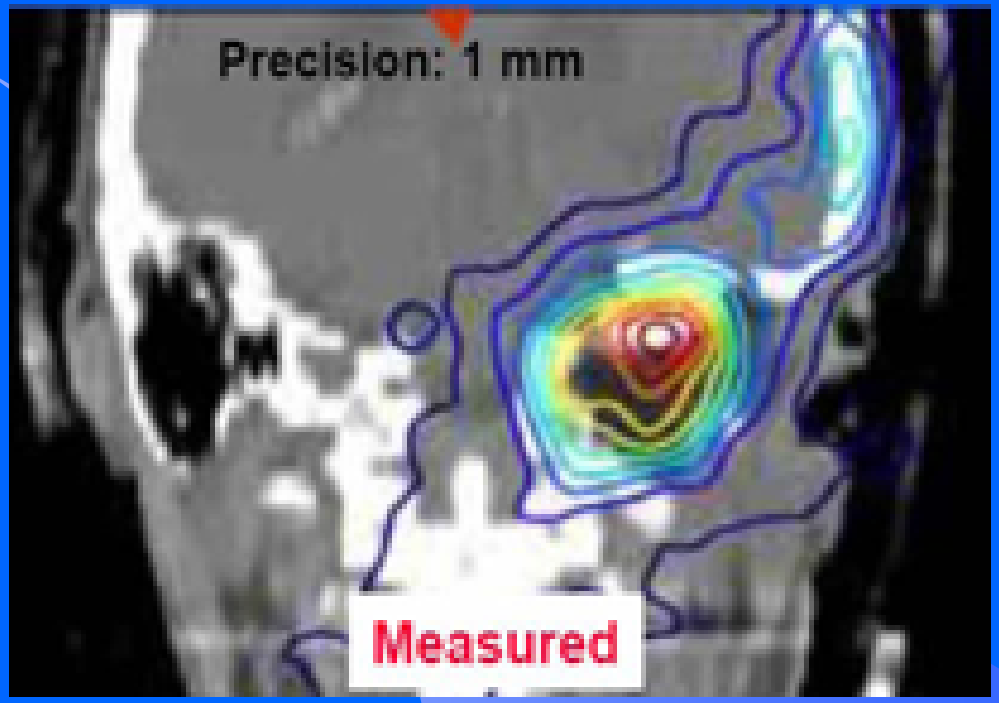


Physics and results of in-beam-PET

Wolfgang Enghart et al.

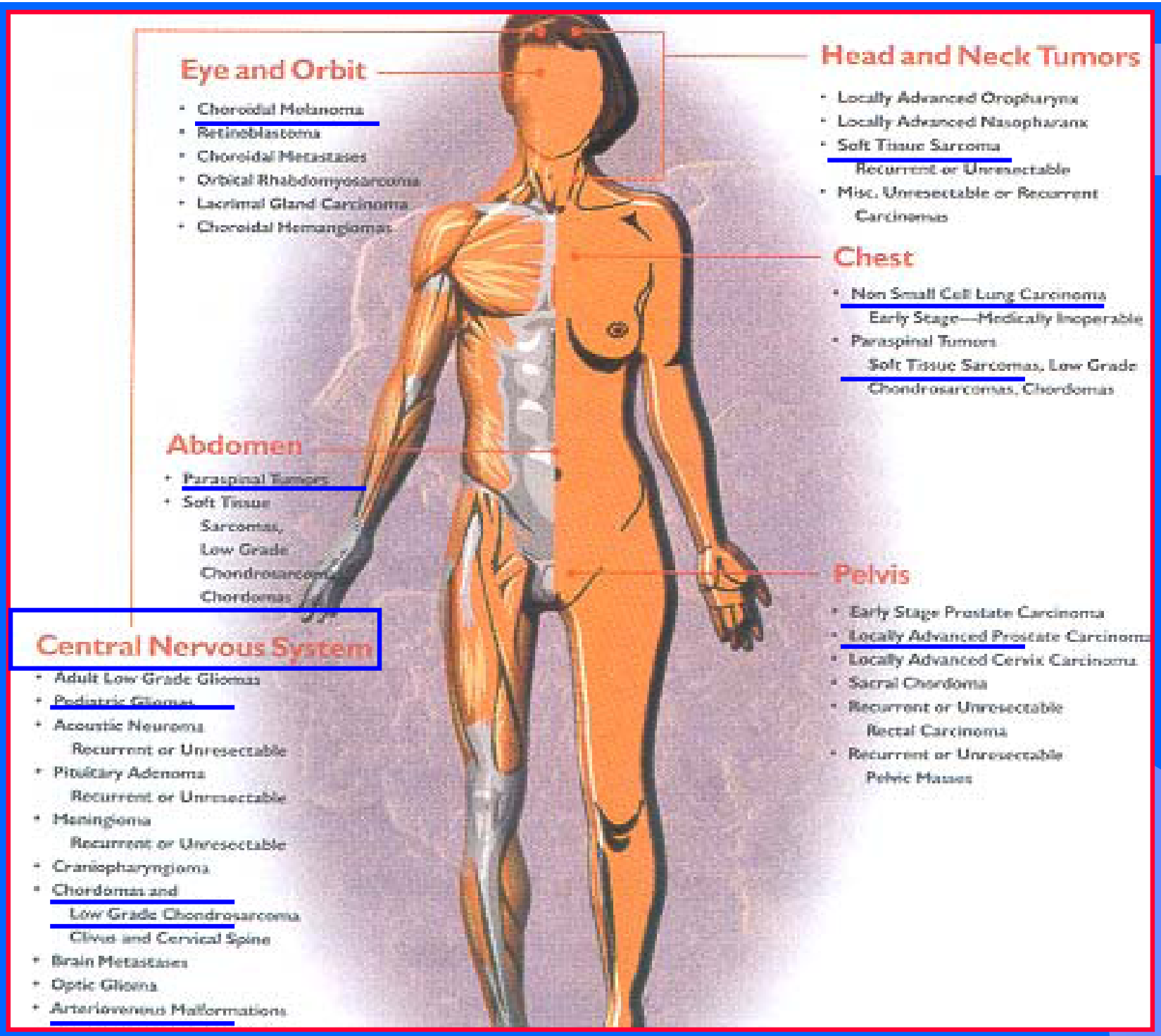
Dresden





Potential patients in Europe

The site treated with hadrons



In the world

protontherapy:

55'000 patients

carbon ion therapy

4400 patients

BUT

less than 1% with 'active' dose distribution systems

at PSI and GSI

with spot/raster scanning

Indication	End point	Results photons	Results carbon HIMAC-NIRS	Results carbon GSI
Chordoma	local control rate	30 – 50 %	65 %	70 %
Chondrosarcoma	local control rate	33 %	88 %	89 %
Nasopharynx carcinoma	5 year survival	40 -50 %	63 %	
Glioblastoma	av. survival time	12 months	16 months	
Choroid melanoma	local control rate	95 %	96 % (*)	
Paranasal sinuses tumours	local control rate	21 %	63 %	
Pancreatic carcinoma	av. survival time	6.5 months	7.8 months	
Liver tumours	5 year survival	23 %	100 %	
Salivary gland tumours	local control rate	24-28 %	61 %	77 %
Soft-tissue carcinoma	5 year survival	31 – 75 %	52 -83 %	

Table by G. Kraft - 2007

(*) Preservation of eyesight

Elective indications for carbon ion therapy from HIMAC and GSI

Hirohito H. Tsujii (May 2007):

for all these tumours we can obtain a 90% local control with no severe complications

- **Chordoma / low grade chondrosarcoma**
- **Malignant salivary gland tumors**
- **Malignant melanoma of the paranasal sinus**
- **Soft tissue sarcomas and bone tumors**
- **Lung cancer (85 patients treated in 1 fraction: NO REPAIR!)**
- **Liver tumors**
- **Prostate carcinoma**

Numbers of potential patients

X-ray therapy (40-50 electron linacs)

every 10 million inhabitants: 20'000 pts/year

Protontherapy

12% of X-ray patients 2'400 pts/year

Therapy with Carbon ions for radio-resistant tumour

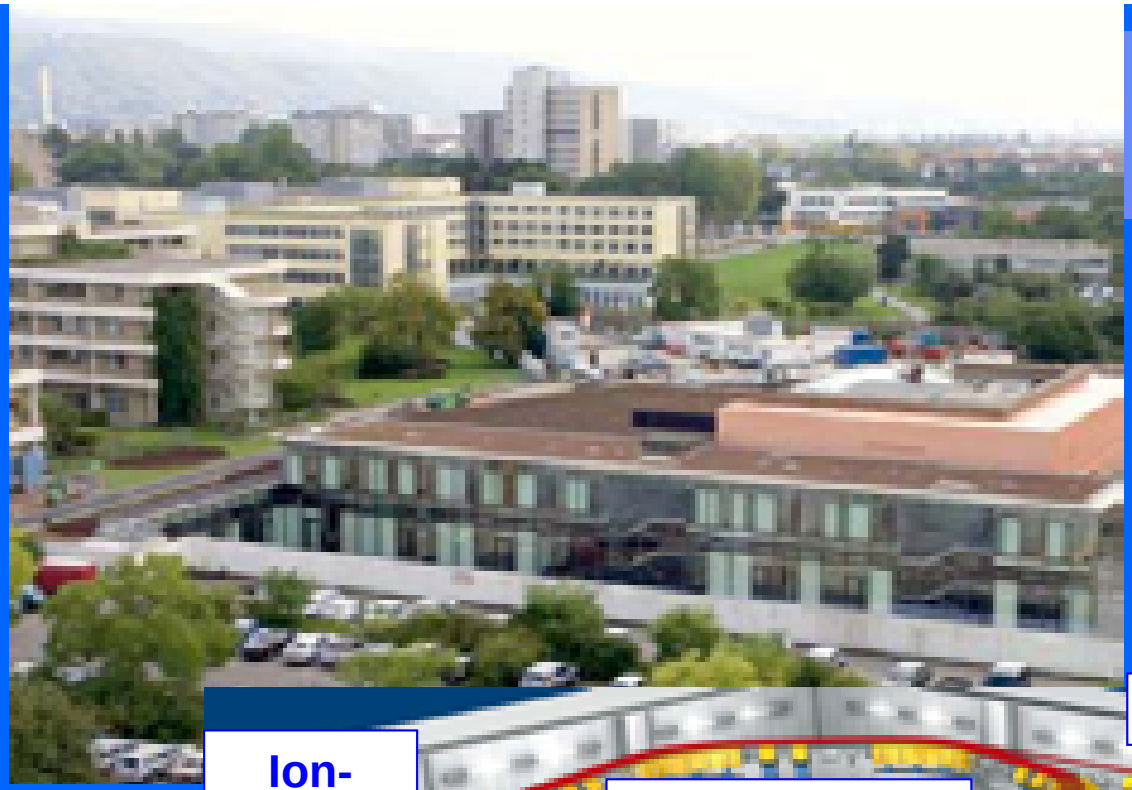
3% of X-ray patients 600 pts/year

TOTAL every 10 M **about 3'000 pts/year**

(*) Combining studies made in Austria, Germany, France, Italy and Sweden - ENLIGHT

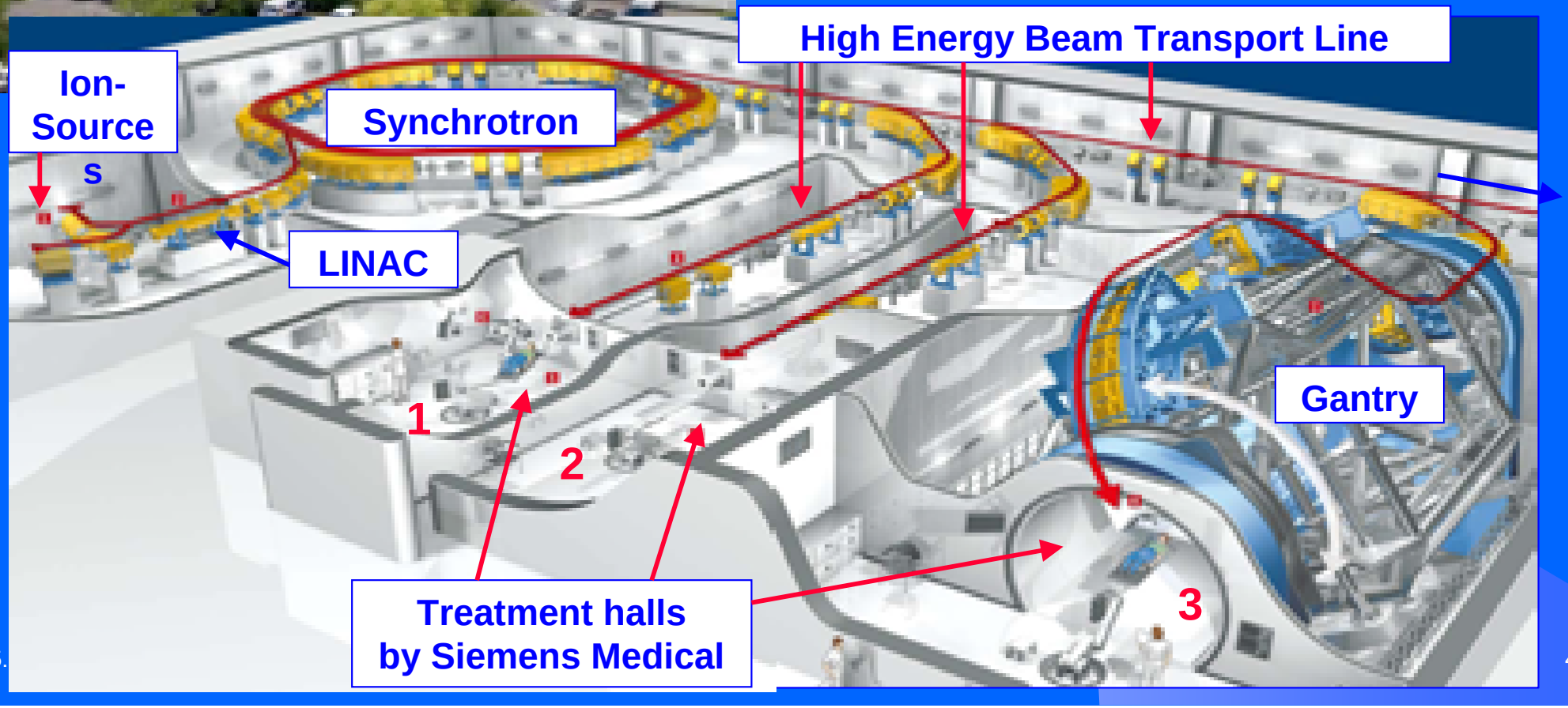
European 'dual' centres for carbon ions and protons

HIT at Heidelberg: first beams in May 2007

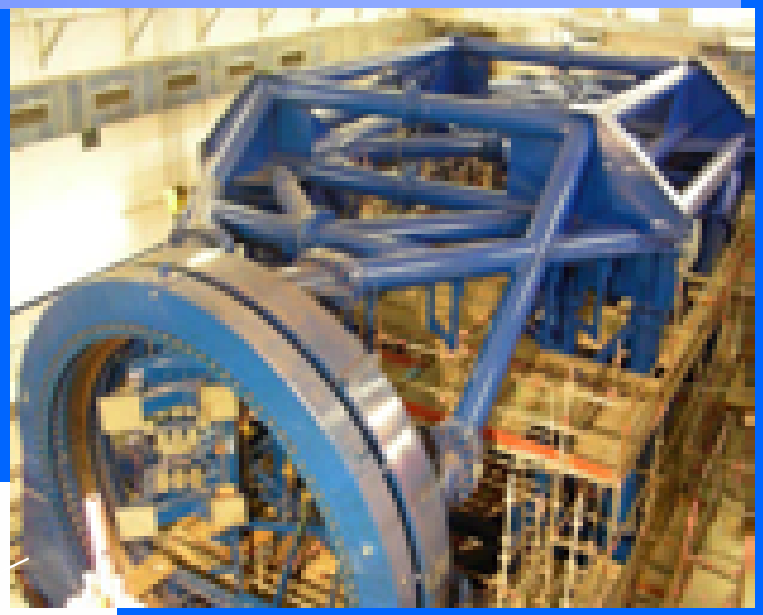


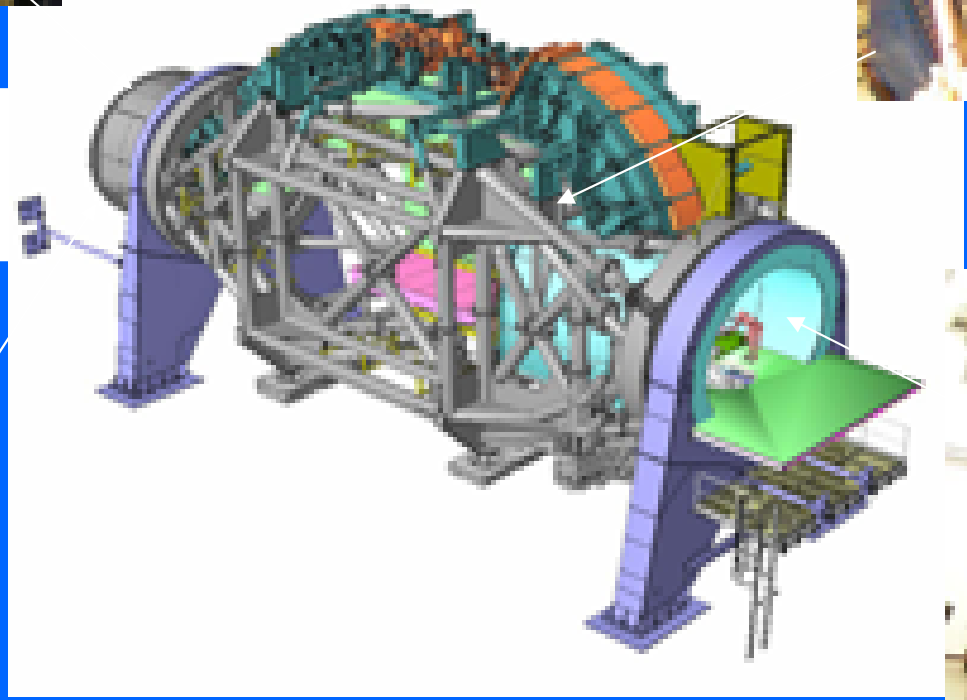
First beam extracted

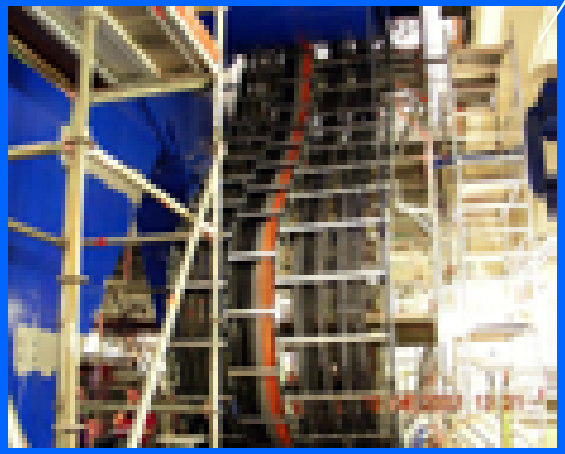
First patient: beginning 2008

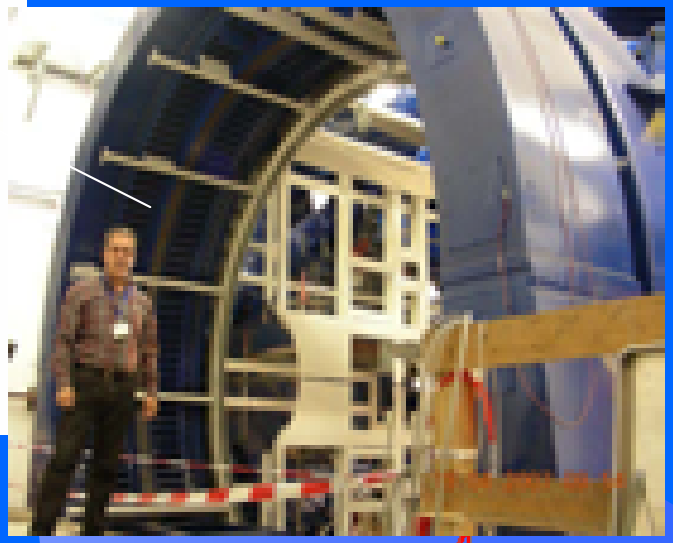


Heidelberg ion gantry: 600 tons and 400 kW







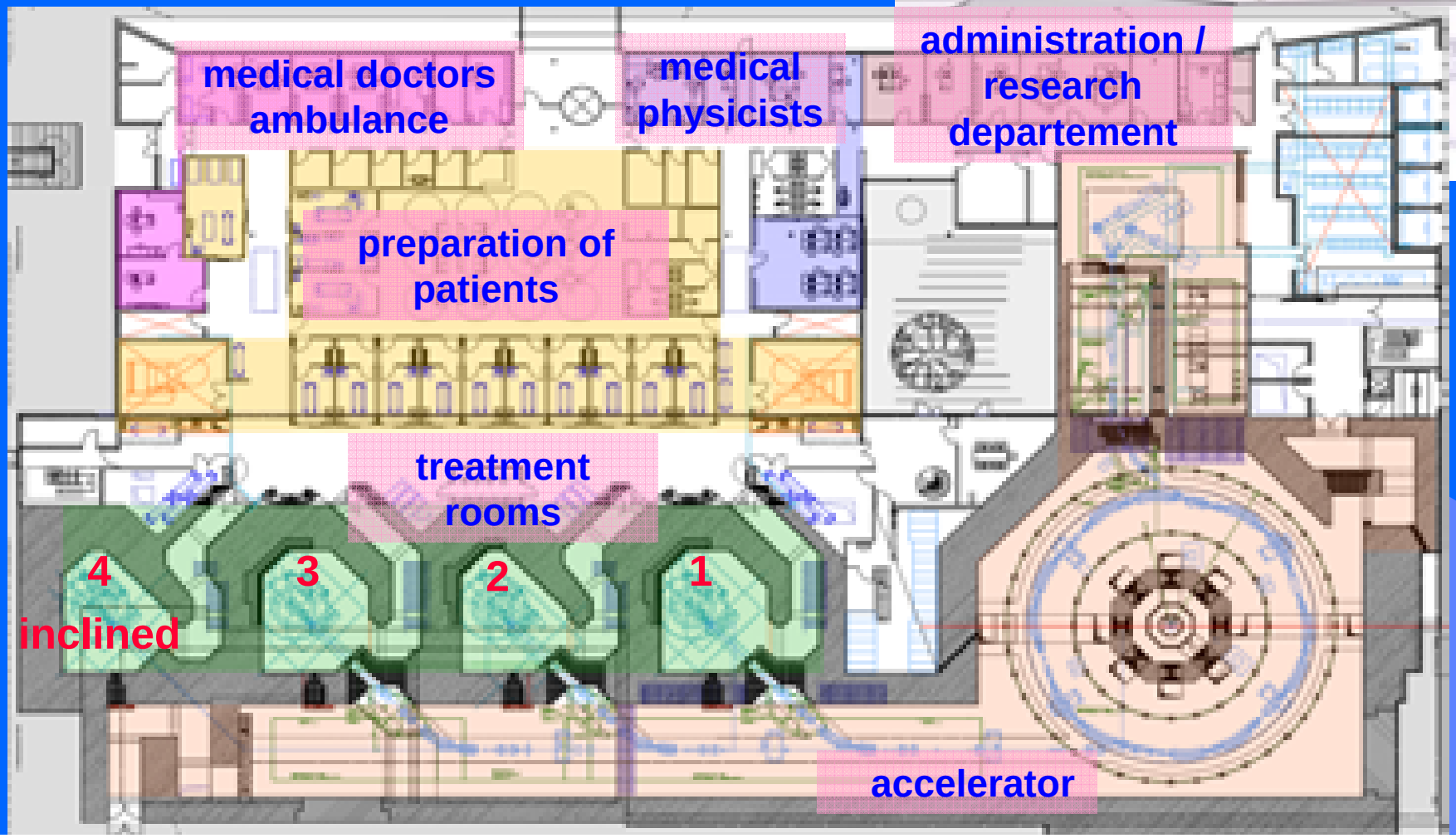


MT AEROSPACE

Siemens Medical is building for 2010 a 'dual' centre in Marburg

Klinikum Giessen/ Marburg GmbH

In 2003 GSI has passed to Siemens Medical its patents and know-how



TERA programmes since 1992

TERA has proposed and designed the 'dual' National Centre for carbon ions and protons

↓

1. CNAO is being built in Pavia

TERA has introduced and developed a novel accelerator:

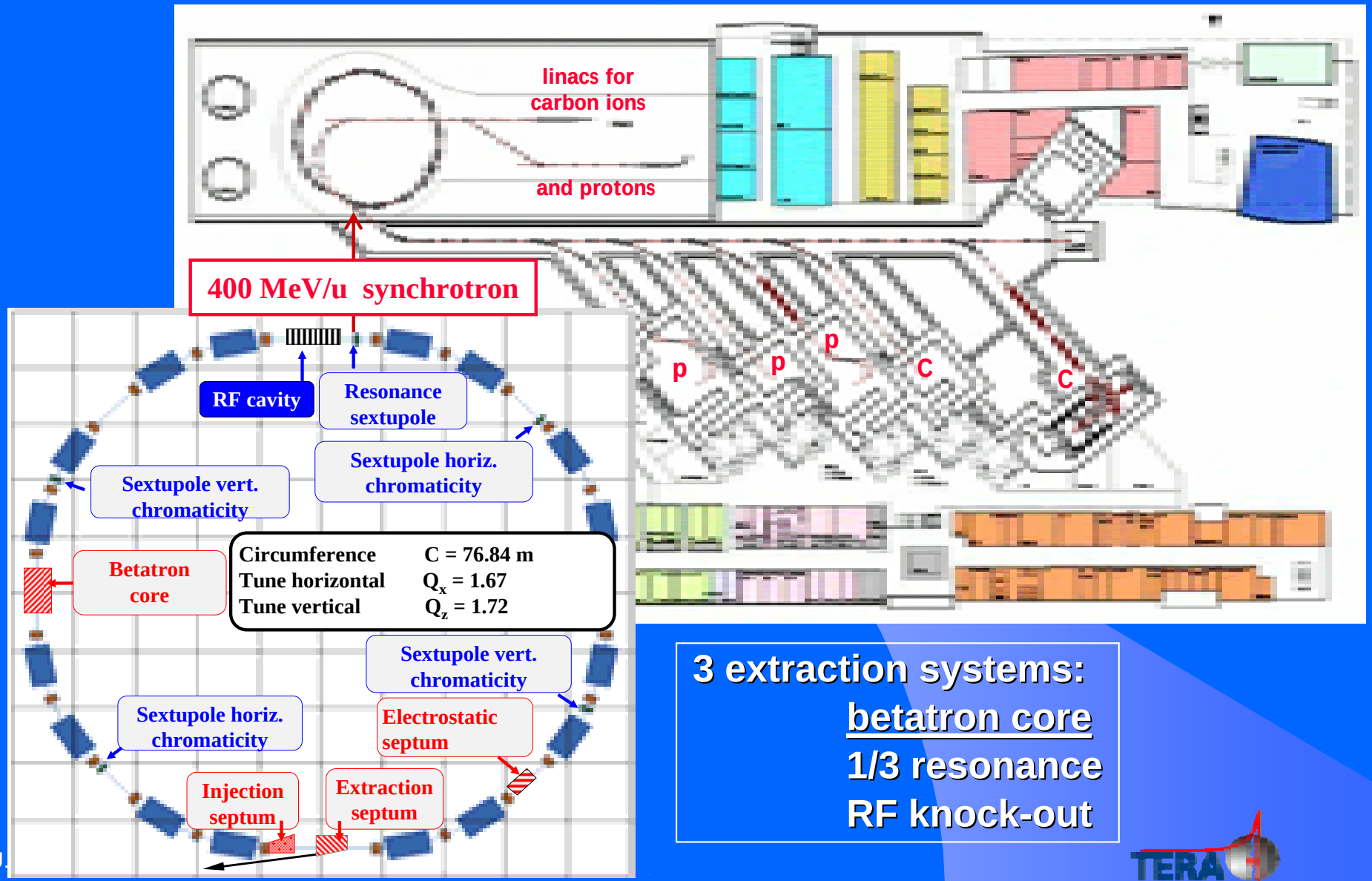
↓

2. Fast cycling "cyclinacs" for protons and carbon ions

PIMMS at CERN in 1996 - 2000

CERN–TERA–MedAustron Collaboration for optimized medical synchrotron

Project leader: P. Bryant



3 extraction systems:
- betatron core
- 1/3 resonance
- RF knock-out

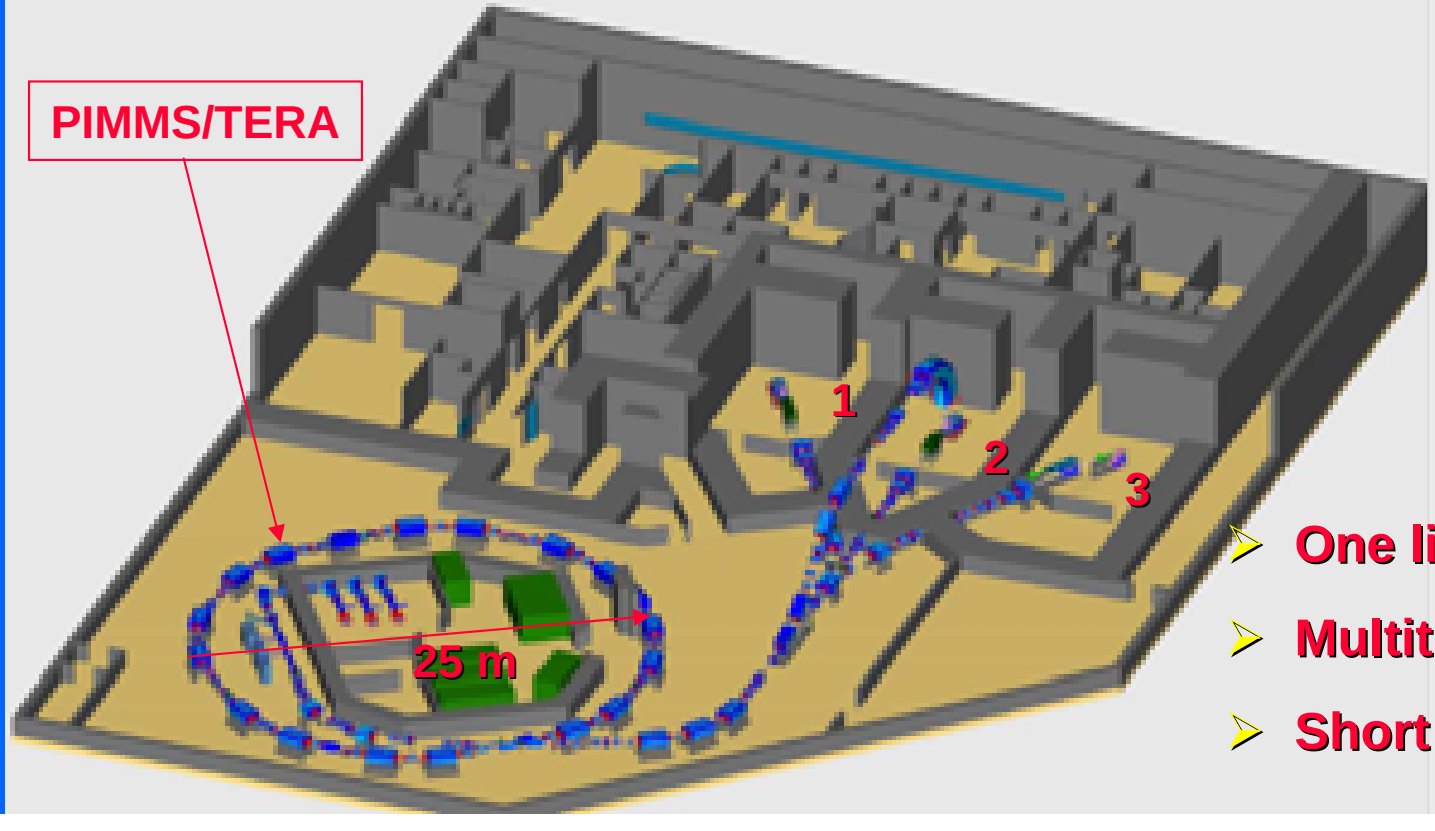
CNAO = Centro Nazionale di Adroterapia

CNAO Foundation created by the Italian Government in 2001:

4 Hospitals in Milan, 1 Hospital in Pavia and TERA

Since 2004 INFN is Institutional Participant with important construction responsabilities

In October 2003 TERA passed to CNAO the design of CNAO (3000 pages) and 25 people



PIMMS/TERA

- **One linac à la GSI inside the ring**
- **Multiturn injection**
- **Short beams**

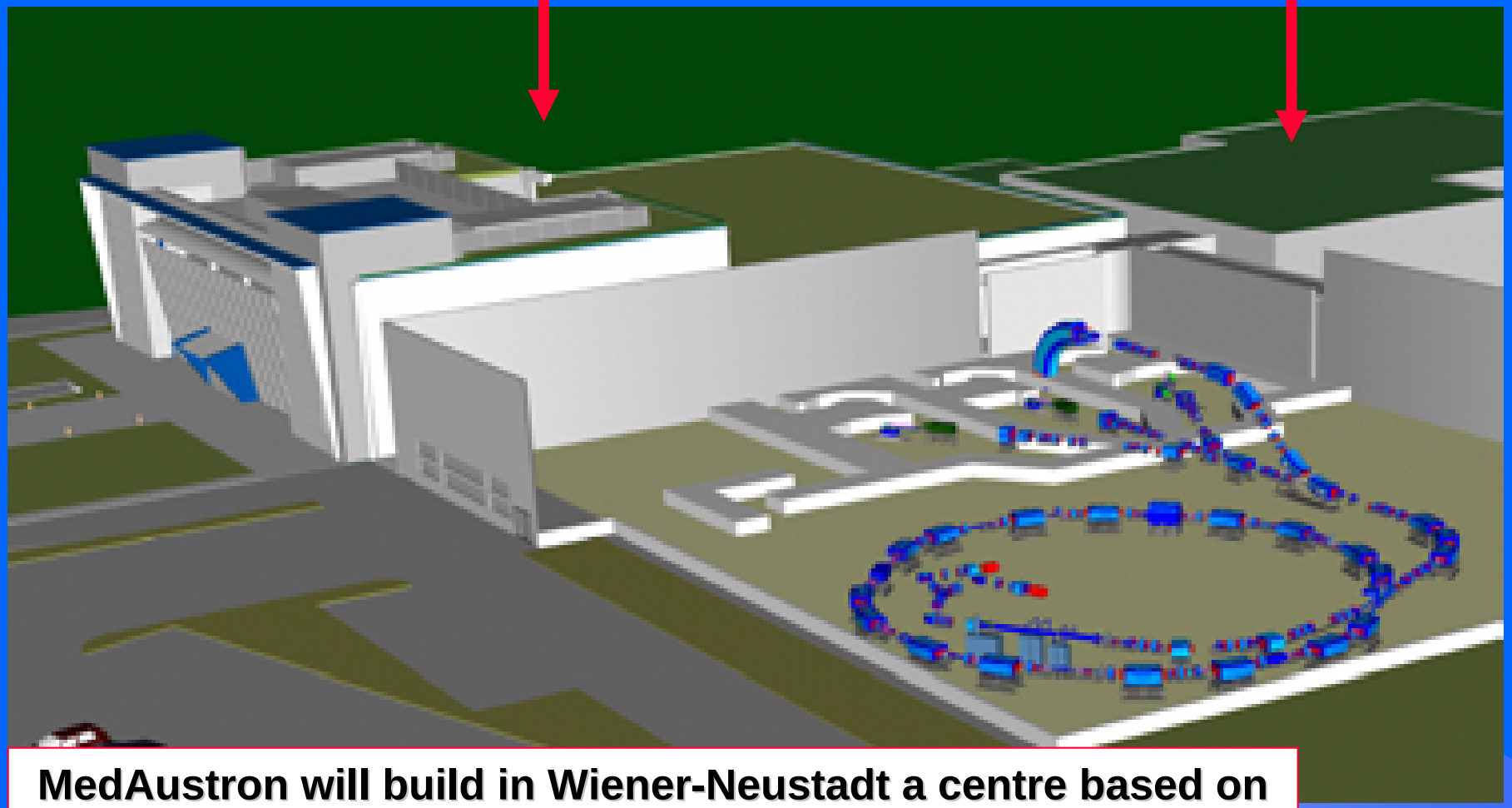
The CNAO Foundation builds the Centre in Pavia

President: Erminio Borloni

Medical Director: Roberto Orecchia Technical director: Sandro Rossi

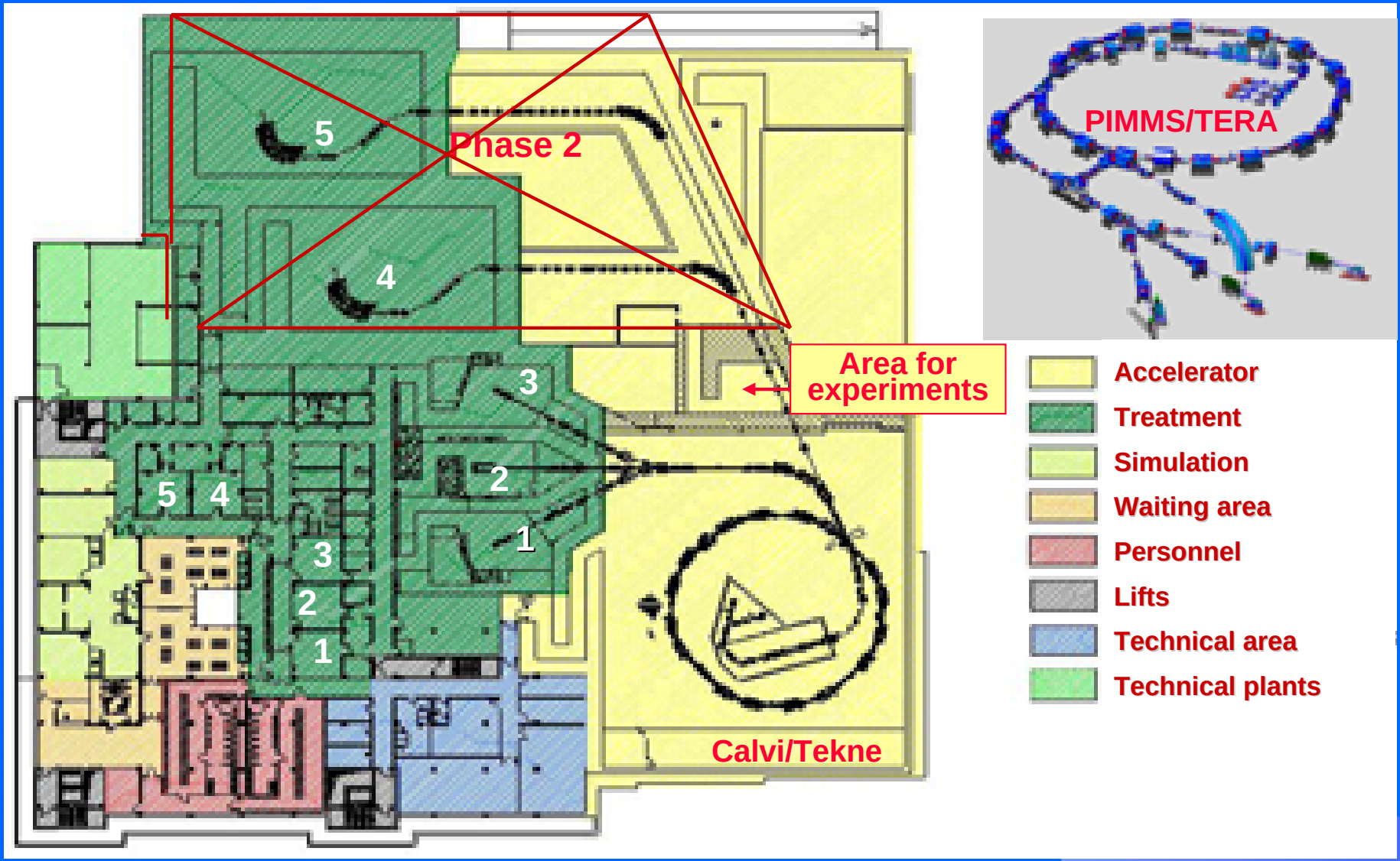
Hospital building

High-tech building



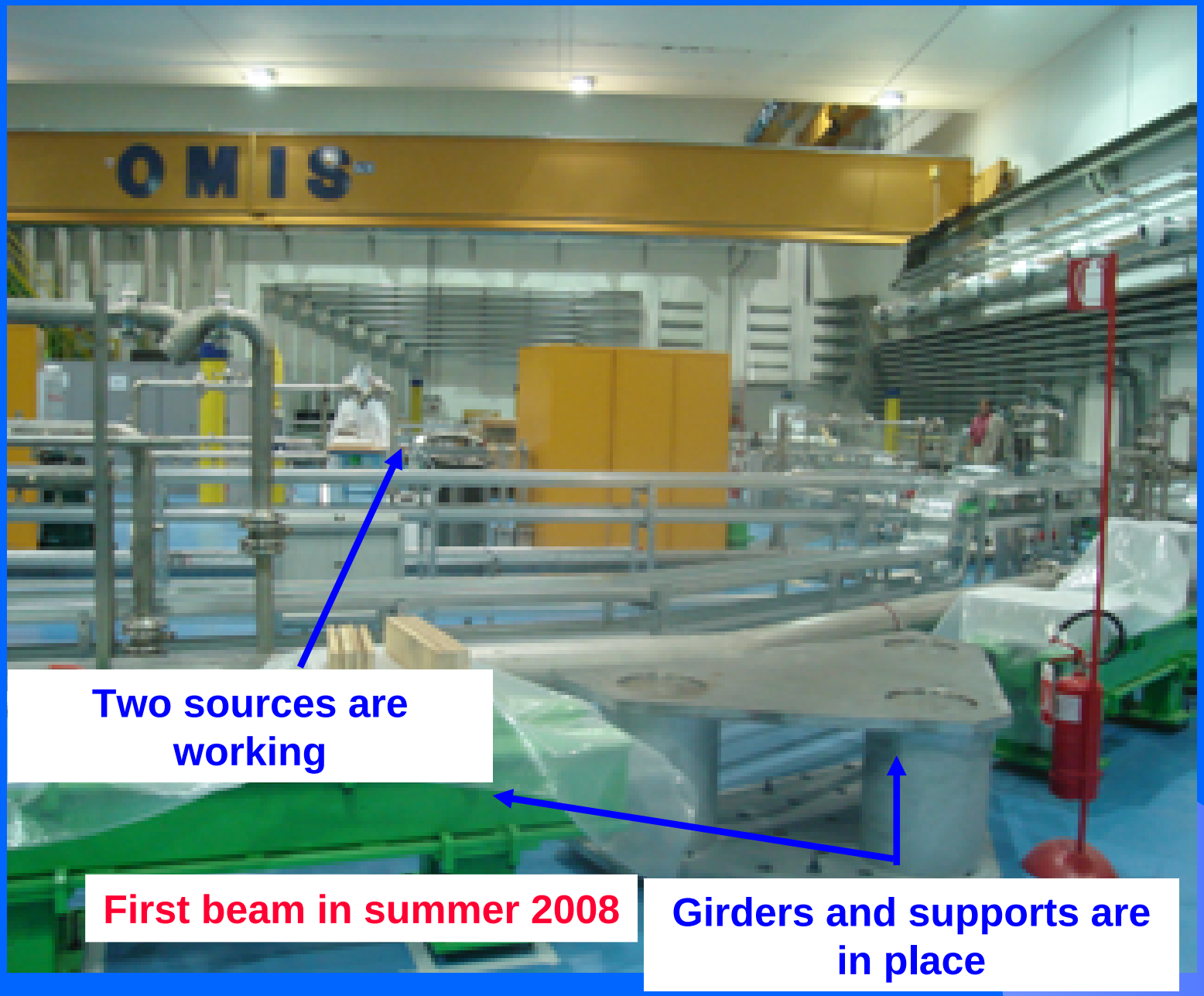
MedAustron will build in Wiener-Neustadt a centre based on the CNAO construction drawings

Synchrotron 'dual' solution for carbon ions and protons by TERA



CNAO in November 2007

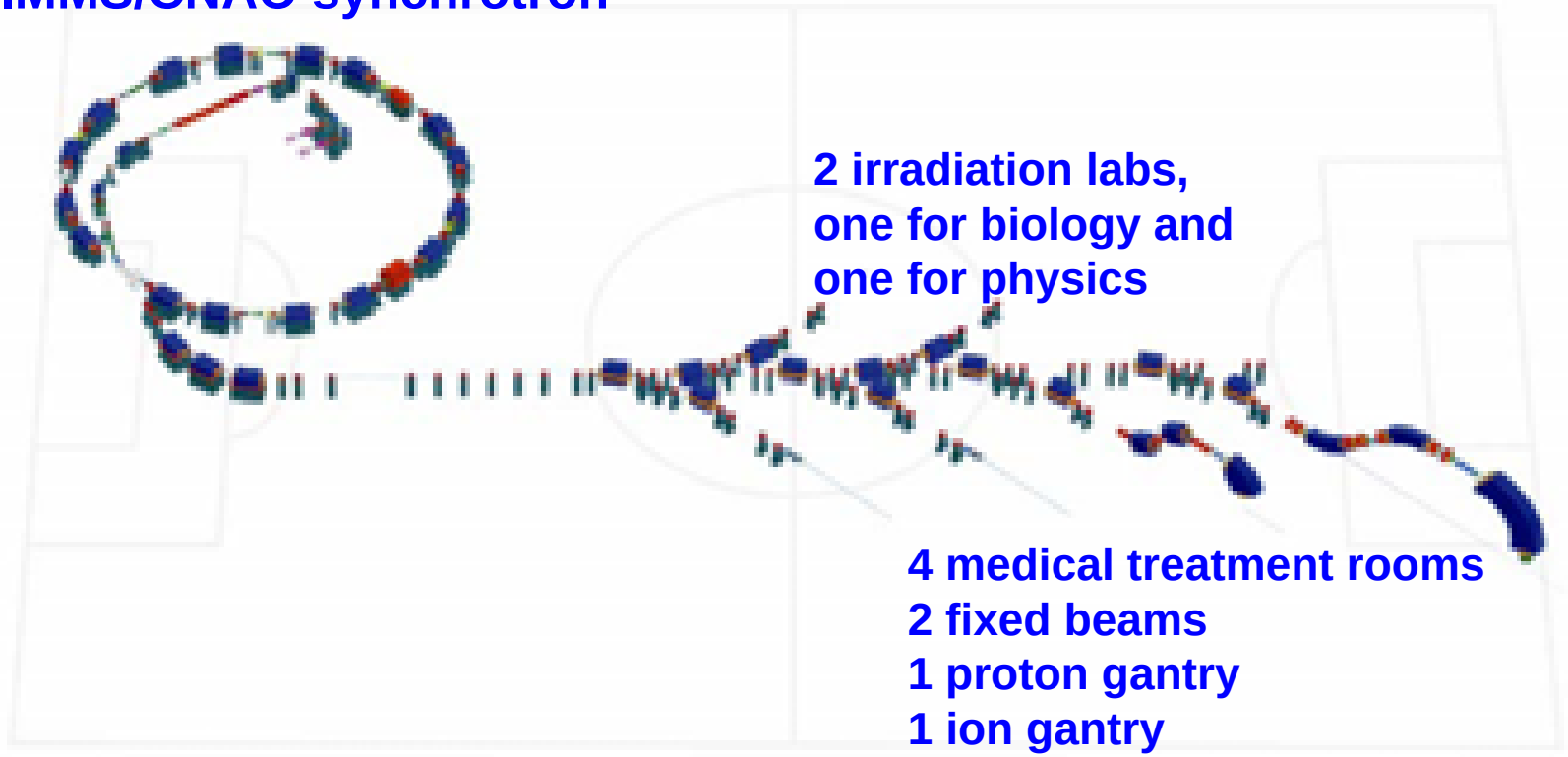
The synchroton vault



In 2007 MedAustron has been approved for Wiener Neustadt

2007: CNAO - MedAustron agreement on the acquisition of the construction drawings

PIMMS/CNAO synchrotron



2 irradiation labs,
one for biology and
one for physics

4 medical treatment rooms
2 fixed beams
1 proton gantry
1 ion gantry
1.200 patients per year

Projet ETOILE

In 2007 approved for construction in Lyon

Tendering in 2008

Present status of ETOILE

www.projet-etoile.fr

Pr Jacques BALOSSO

Medical director

ENLIGHT = European Network for Light Ion Therapy

- **Initiated with a CERN meeting in Feb.2002: Austria, France, Germany, Italy, Sweden, CERN,GSI, ESTRO**
- **Financed by the Commission for 2002-2005**
- **Transformed into the 'ENLIGHT^{++} Platform' in 2006 – see www.cern.ch/enlight**
- **Coordinator of ENLIGHT^{++} : Manjit Dosanjh (CERN)**
- **2007: approval of the Marie Curie Training Network PARTNER**
- **2008: submission of ULICE = Union of Light Ion Centres in Europe around Heidelberg and Pavia**